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CONTENTS

		Page
Volcanic Ash Over the Caribbean, June 1951	William F. Brown	59
Thunderstorm Forecasting in the Atlanta, Ga., Area	Robert G. Beebe	63
The Weather and Circulation of April 1952	Major Donald E. Martin	70
The Prolonged Rain Period over the Atlantic Coastal States, April 23-29, 1952	I. A. Carr	73
Charts I-XV		

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MONTHLY WEATHER REVIEW

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VOLCANIC ASH OVER THE CARIBBEAN, JUNE 1951

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[Manuscript received January 18, 1952]

In the latter half of June 1951 an extensive haze layer moved over the Caribbean Sea and spread northward to the central and eastern United States. Density of the haze was such that horizontal visibility was less than a mile in some places; haze was reported to 14,000 feet elevation, and aircraft crews were often forced to resort to instrument flight over much of the Caribbean area. The condition clearly was not the usual haze frequently found beneath the trade-inversion of the tropics.

Examination of synoptic reports from Dakar, Africa, for the week preceding arrival of the haze over the Antilles revealed no indication of a dust storm or other possible cause of the unusual phenomenon. It was thus necessary to look further for the source of the haze. News reports of a volcanic eruption in the Cape Verde Islands were recalled and it developed that this was almost certainly the true origin of the haze.

The British Meteorological Office at Trinidad, B. W. I., furnished the information that on the morning of June 12, 1951, a volcanic eruption occurred on Fogo Island, in the Cape Verde group. The activity began with an explosion and earthquake; a cloud column from the craters built to a height of 25,000 feet; and ashes were observed falling on Fogo and nearby Bravo Island. By June 17 activity was decreasing but there were still active craters with flames and associated clouds. A secondary peak of activity was noted on June 26, the volcanic cloud ascending to 12,000 feet this time, after which the volcano gradually subsided.

Figure 1 reproduces the complete set of detailed charts used in calculating the movement of the haze from June 15 to 26. Figure 2 is a summary chart showing the spread of the haze. During the first 5 days the haze condition was tracked mostly by aircraft reports as the area it then covered has few land reporting stations. After the haze reached the southern Gulf States and Florida on June 20, land reports of course were available; the 1830 GMT reports were used in tracking the movement, for at this time any local restriction to visibility would tend to be dispersed.

Several interesting features of the spread of the haze are revealed by figures 1 and 2. Unusual haziness was reported in the Barbados-St. Lucia-St. Vincents area of the Lesser Antilles beginning on June 15 and examination of wind flow charts for the Cape Verde to Antilles portion of the Atlantic indicates that its source could very well have been the Fogo eruption. The distance is 2,300 miles and elapsed time between the eruption and initial appearance of the haze in the Windward Islands is consistent with the indicated average wind speed of about 25 knots.

From the Windward Islands the haze-bearing stream moved west-northwestward at a speed of about 28 knots,

EXPLANATION OF SYMBOLS USED IN FIGURE 1

In-flight and post-flight reports:
- Aircraft or route identification (for example, PAA 508 or MIQ/KIN)
- Flight altitude (FA) in hundreds of feet.
- Time of flight, GMT (Z)
- Conditions of flight, IFR (instrument), VFR (visual)
- Clouds observed
  - Type–standard cloud abbreviations (U. S. Weather Bureau, Circular S).
  - Amount–in eighths of sky cover or U. S. Weather Bureau sky cover symbol (U. S. Weather Bureau Circular N, 6th ed. revised) (example: 2 Cu=2/8 cumulus and 2/5 Cu=2/8 to 5/8 cumulus).
  - Height–in hundreds of feet top/base (XX=unknown).
- Visibility, horizontal–in miles
- Wind at flight altitude (or given altitude)–direction (degrees)/speed (knots).

Land station reports:
- Visibility, horizontal–statute miles coded in eighths of miles up to 10 mi. (80=10–12 mi., 81=13–24 mi., 82=25–39 mi.) (U. S. Weather Bureau Synoptic Code, effective January 1, 1949).
- ∞–dry haze present.

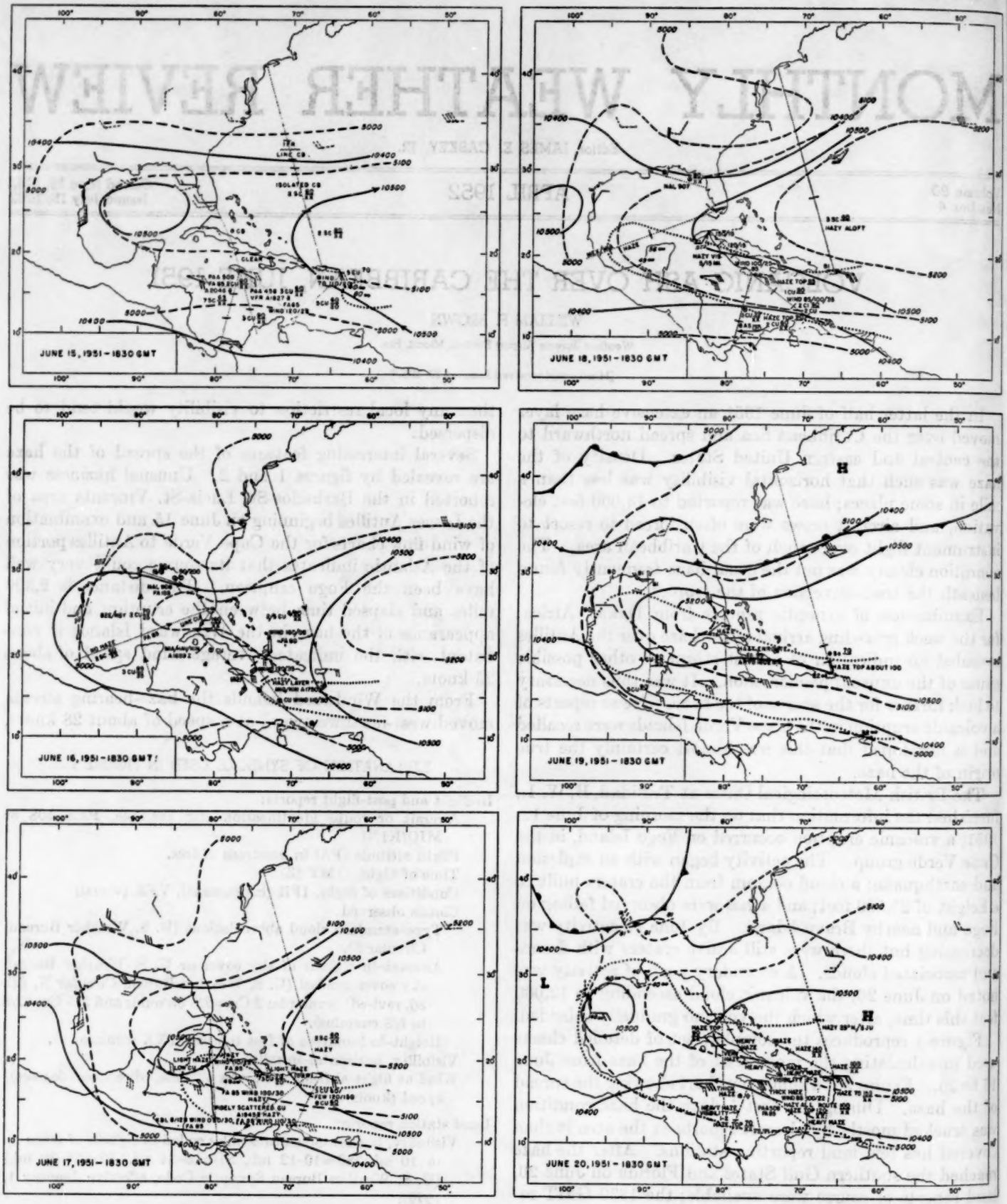
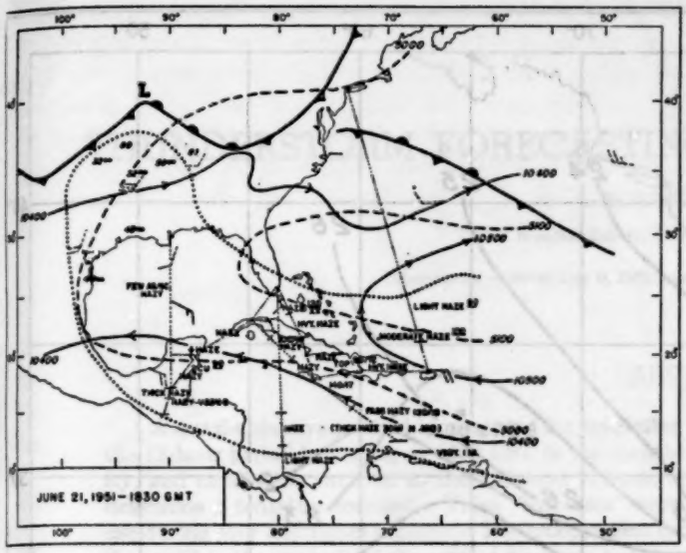
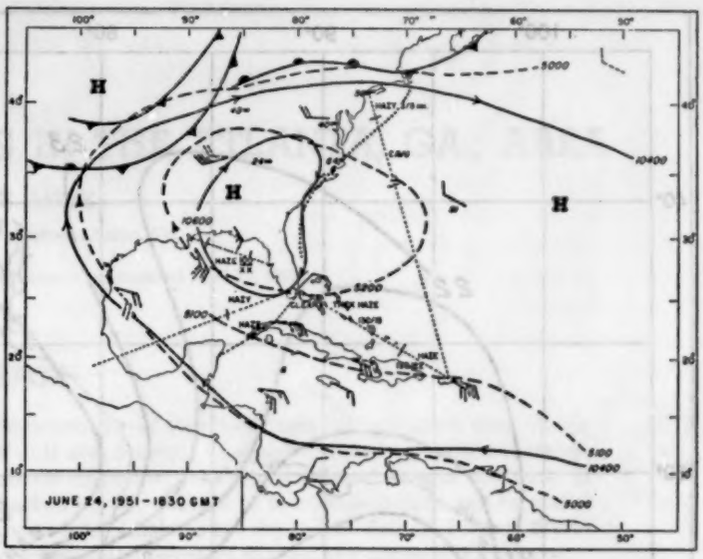
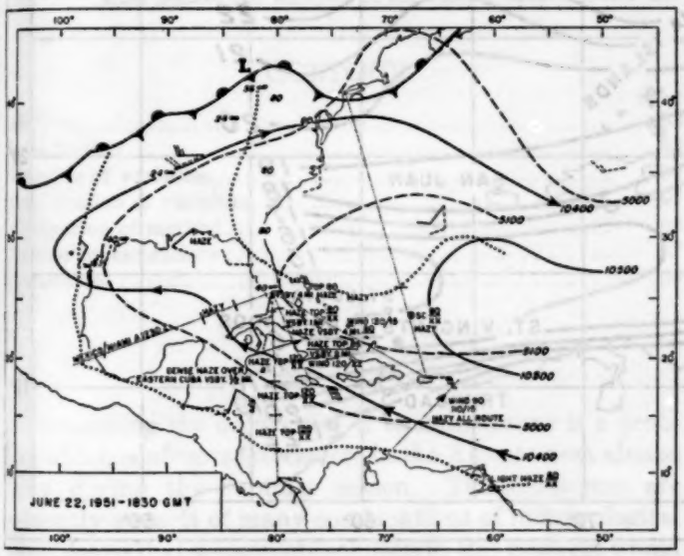
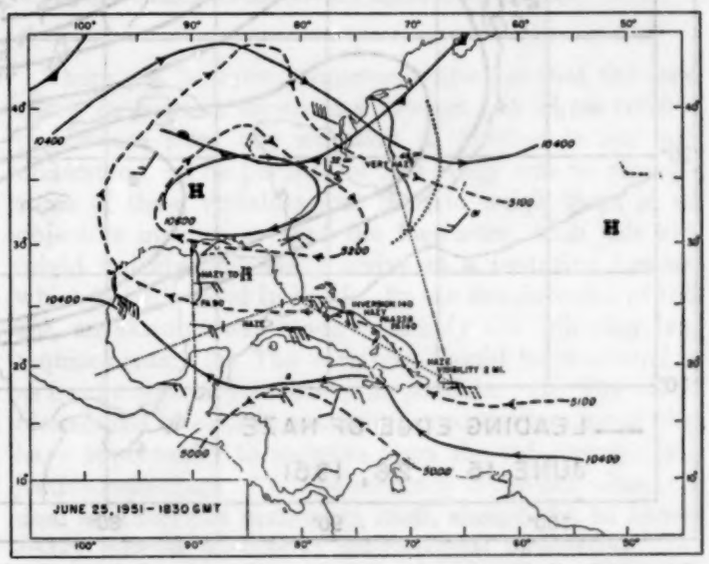


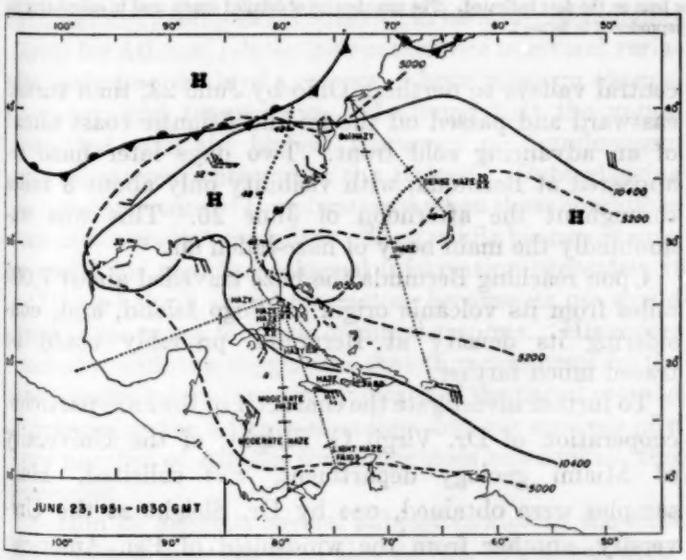
FIGURE 1.—Daily charts showing leading edge of haze layer (heavy dotted line) as determined by aircraft and weather station reports, June 15–26, 1951. Solid lines are the 700-mb. 5 knots). Thin dotted lines are flight paths.

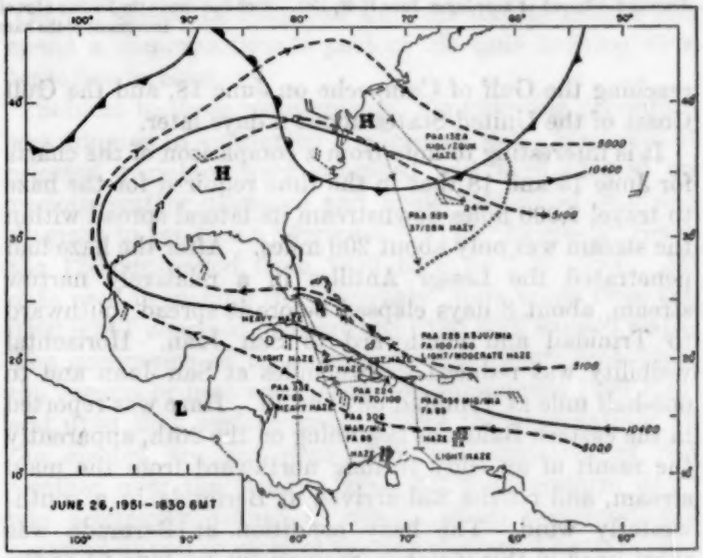












contours labelled in feet, dashed lines are the 850-mb. contours. Solid wind symbols are 10,000-ft. winds, dashed symbols are 5,000-ft. winds (full barb=10 knots, half barb=
See page 59 for explanation of plotted reports.

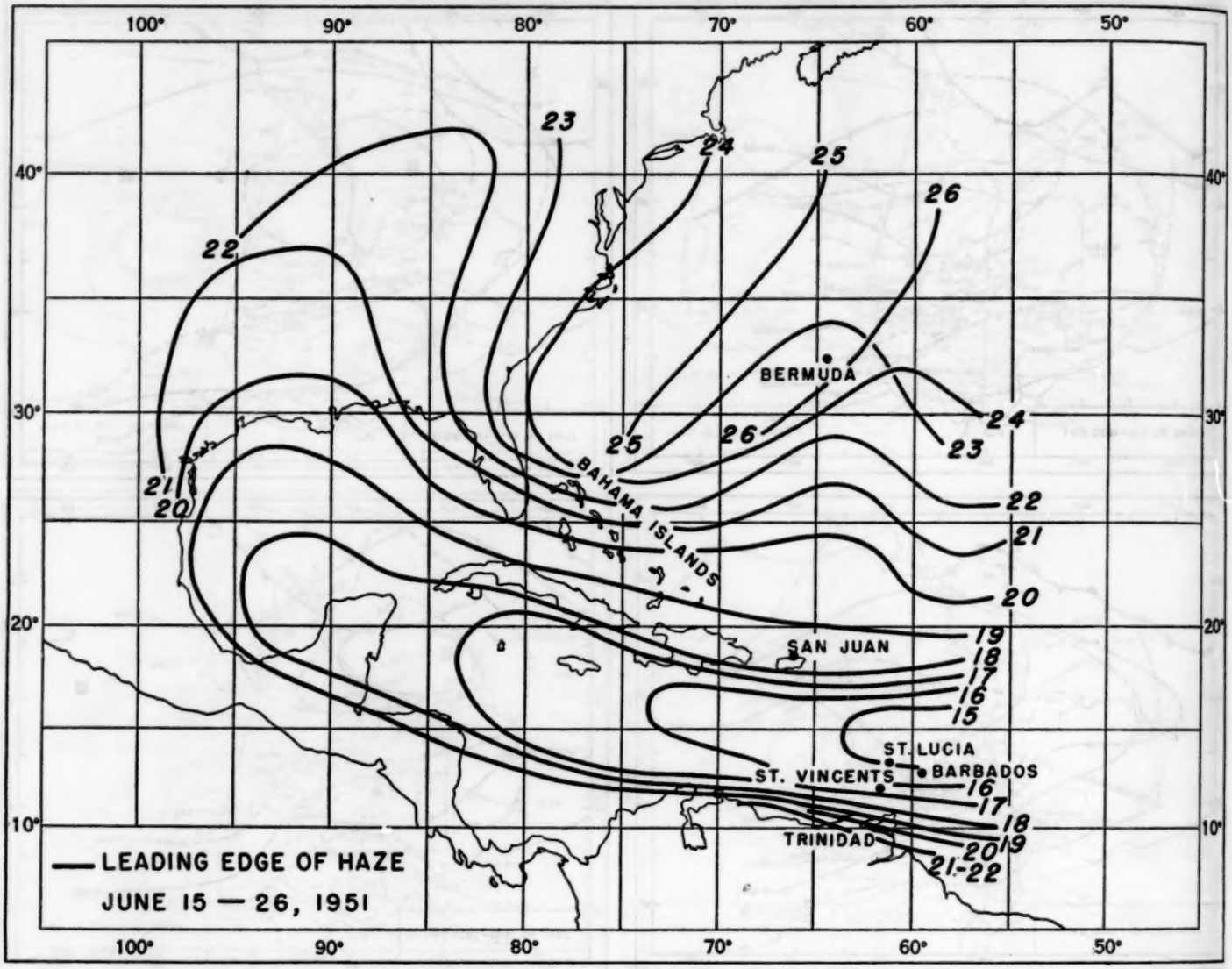


FIGURE 2.—Spread of haze layer, June 15-26, 1951. Each line shows the leading edge of the haze on the date indicated. The complete set of detailed charts used in calculating the movement of the haze is reproduced in figure 1.

reaching the Gulf of Campeche on June 18, and the Gulf Coast of the United States about 2 days later.

It is interesting to note from a comparison of the charts for June 15 and 18 that in the time required for the haze to travel 2,000 miles downstream its lateral spread within the stream was only about 200 miles. After the haze had penetrated the Lesser Antilles in a relatively narrow stream, about 3 days elapsed before it spread southward to Trinidad and northward to San Juan. Horizontal visibility was reduced to two miles at San Juan and to one-half mile at Trinidad on June 19. Haze was reported in the eastern Bahamas beginning on the 20th, apparently the result of an eddy turning northward from the main stream, and on the 23d arrived at Bermuda in a southwesterly wind. The hazy condition at Bermuda was short-lived in this instance, moving out on June 24 as the wind veered to northwest.

Under the influence of circulation systems existing at the time, the forward edge of the main stream of haze spread northward from the Gulf of Mexico through the central valleys to northern Ohio by June 23, then turned eastward and passed off the middle Atlantic coast ahead of an advancing cold front. Two days later haze reappeared at Bermuda, with visibility only about 3 miles throughout the afternoon of June 26. This was undoubtedly the main body of haze-laden air.

Upon reaching Bermuda the haze travelled about 7,000 miles from its volcanic origin on Fogo Island, and, considering its density at Bermuda, probably could be traced much farther.

To further investigate the character of the haze particles, cooperation of Dr. Virgil G. Sleight, of the University of Miami geology department, was solicited. Haze samples were obtained, one by Dr. Sleight at the University, another from the windshield of Pan American World Airways flight 226, flying between San Juan and Miami on June 22. Microscopic examination of the samples indicated that they were similar and both of the nature of volcanic ash.

THUNDERSTORM FORECASTING IN THE ATLANTA, GA., AREA

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[Manuscript received July 9, 1951; revised manuscript received April 17, 1952]

ABSTRACT

A quasi-objective method is presented for predicting the occurrence of thunderstorms in the Atlanta area during the 12-hour period beginning at 1330 EST in the months of July and August. Variables measuring moisture, stability, and circulation patterns at the 850- and 700-mb. levels are combined through the use of scatter diagrams to determine a tentative forecast. These "forecasts" were checked on two seasons of independent data and in actual use during four additional seasons. The independent data were later added to the dependent data and it was found that neither the analysis of the scatter diagrams nor the accuracy of the forecasts showed any appreciable change.

CONTENTS

	Page
Abstract	63
Introduction	63
Selection of variables	64
Combination of variables	64
Verification of method	65
Further investigations	67
Conclusion	69

INTRODUCTION

Forecasting the occurrence of thunderstorms is a problem which confronts forecasters in the Atlanta area almost daily during the summer season. Thunderstorms are evidently a result of many combinations of meteorological variables so that a complete solution to this problem would be exceedingly complex. Carlin [1], in his study of thunderstorms for Atlanta, relates their occurrence to several variables including sea level pressure, 3-hour pressure change, dewpoint, and temperature. He found that the values associated with the highest frequency of thunderstorm occurrence were those near the normal. Data showing the nonoccurrence of thunderstorms when these conditions were met were not compiled. Thus, while his report may be useful for the climatological information presented, it is of little help in actual forecasting because its use would result in too many forecasts of thunderstorms. His report concludes with the suggestion that thunderstorms in the area usually can be forecast by means of the parcel method of evaluating the Atlanta sounding, but our analysis of a large number of Atlanta soundings does not confirm this conclusion.

Norton [2] suggests several subjective aids to the forecaster in this area but such aids do not, in general, accurately indicate the relative weight to be applied to the different meteorological variables. In fact, unless such rules or aids are carefully tested, they may be misleading at times.

There are, however, numerous variables that the forecaster employs to arrive at a forecast but whose relative importance from one situation to another is not well understood. The purpose of this study was to measure some of these variables and then to weigh them in an objective manner so that the forecaster, with this aid, might quickly and easily arrive at a tentative forecast which is fairly good in itself. In the development of this aid, an attempt was made to satisfy the following four requirements: (1) The variables should be measured in as nearly objective a manner as possible. (2) The variables should be ones in common use so the forecaster may have opportunity to improve upon the aid through subjective reasoning. (3) The accuracy of the aid, when it is used as a forecast method in itself, should not be appreciably inferior to that of conventional forecasting. (4) The aid should be simple so that the forecaster does not spend a disproportionate part of his time arriving at a tentative forecast.

Subject to these requirements, the following procedure was adopted in developing the forecast aid. Measures of selected variables were compiled and then plotted on various scatter diagrams and finally combined into one diagram to produce a "forecast." The "forecasts" cover the 12-hour period from 1330 EST to 0130 EST. All data used in making the "forecasts" were taken from the 0300 GMT constant pressure and 0130 EST surface maps. The occurrence of thunderstorms was determined from the present or past weather on the subsequent 1930 EST and 0130 EST surface maps. Since the observations at the airport are not necessarily representative of the weather over the Atlanta area, a "thunderstorm day" was arbitrarily defined as one in which thunderstorms occurred at two or more of the five stations, Chattanooga, Birmingham, Macon, Augusta, and Atlanta, or, if one thunderstorm and two or more showers occurred at any of these stations. This area is larger than is desirable but still preferable to verifying on what occurs at a single

station. The months of July and August of 1943, 1944, and 1945 were used to construct the scatter diagrams and the same months of 1946 and 1947 were used as test data.

SELECTION OF VARIABLES

A survey of thunderstorm occurrences at Atlanta shows that the majority occur during the afternoon and evening with relatively few occurrences during the morning hours. Since there are practically no warm frontal passages and few cold frontal passages in this area during the summer season, an important factor contributing to thunderstorm formation would seem to be diurnal heating, either directly or indirectly. However, the insolation available for afternoon heating is nearly constant during these months so that temperature advection and cloud cover play an important part. The use of the parcel method of evaluating the Atlanta sounding is of considerable help to the forecaster but he has been disappointed in these results all too frequently. Our experience suggests that heating from the surface during the daylight hours is not enough in itself to result in widespread thundershowers and thus is in agreement with findings of Byers and Rodebush [3] for Florida thunderstorms. Evidently, there are other factors which determine the difference between isolated thundershowers and numerous ones and which, at the same time, are more easily utilized and measured in an objective study.

At least three other factors which are important in forecasting thunderstorms in this area are (1) the humidity of the air mass, (2) its stability, and (3) the circulation aloft which will result in modification of the first two factors.

The surface dew point at 0130 EST at Atlanta was used as a measure of the humidity of the surface air mass. From a total of 158 cases, it was found that in the 15 cases when the dew point was less than 61° F., no thunderstorms were reported. Therefore, all cases with dew points below 61° were considered as "no-thunderstorm" forecasts and were not further considered. The humidity aloft was measured simply by the mixing ratio (dew points since January 1, 1949) at 850 and 700 mb. from the 0300 GMT sounding at Atlanta. A measure of stability was obtained through the temperature difference between 850 and 500 mb. at 0300 GMT at Atlanta. The change in stability was measured by the 24-hour change in this temperature difference and is positive with increasing instability.

The circulation aloft at both the 850- and 700-mb. levels over a line between Atlanta and Memphis was classified as flat gradient, cyclonic, or anticyclonic according to the following criteria: Flat gradient case—the average winds reported across the line were less than Beaufort force 3; cyclonic case—the average winds were force 3 or stronger and shifted cyclonically across this line, or the contour lines indicated a definite cyclonic shift and had a gradient of at least force 3; anticyclonic case—reported winds were force 3 or stronger with an anticyclonic wind shift or straight flow across this line, and, in this case, the anticyclonic or straight flow prevailed across this line. Some subjectivity is hereby injected into this scheme but this method seemed preferable to any other measure of the circulation that could be devised at the time.

COMBINATION OF VARIABLES

Thus, seven variables have been found which are considered here as measures of factors associated with thunderstorms. As the hypothesis of the relation of these variables to the subsequent occurrence of thunderstorms does not suggest their order of combination, they were paired in 12 scatter diagrams in what seemed to be a logical order. That is, for each of the circulation types, the moisture value at 850 mb. was plotted on a scatter diagram against that at 700 mb., and stability was plotted against the change in stability and the relationships to thunderstorm occurrence were analyzed. There are, of course, many other possible combinations of these variables but the one used here seemed to be satisfactory and no attempt was made to improve the study through different combinations of the same variables.

These variables were combined as shown schematically in figure 1. Six scatter diagrams were used (fig. 2) in which the mixing ratio at 850 mb. (W_{850}) was plotted against that at 700 mb. (W_{700}), but only two of these are used on any one date. The mixing ratios were plotted on one of these diagrams, figure 2a, 2b, or 2c, according

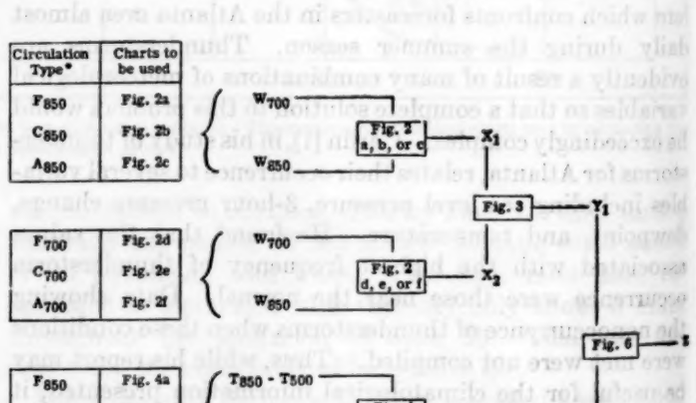

FIGURE 1.—Schematic diagram showing combination of variables. See text for definition of variables.

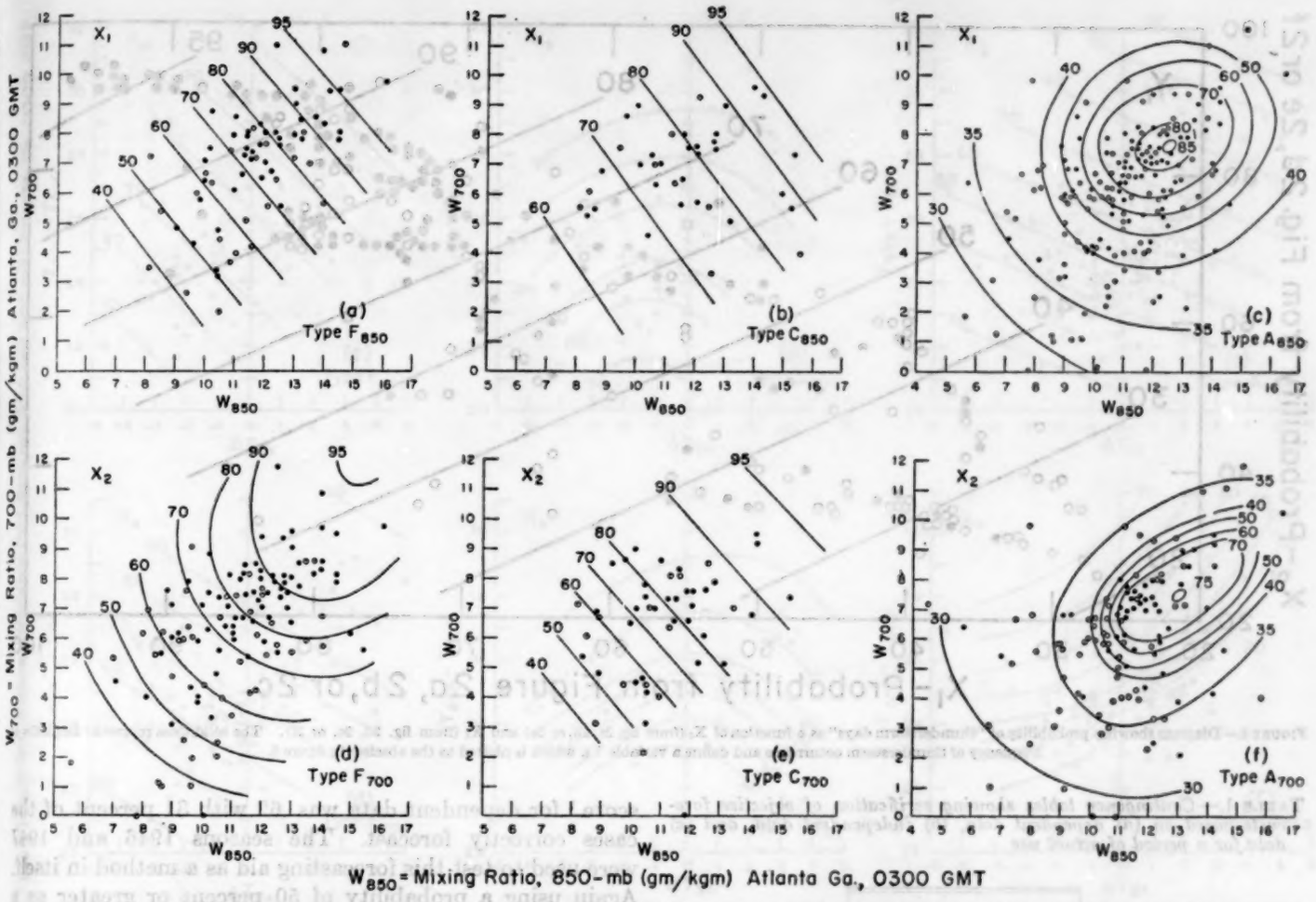
W_{700} = Mixing Ratio, 700-mb (gm/kgm) Atlanta, Ga., 0300 GMT
W_{850} = Mixing Ratio, 850-mb (gm/kgm) Atlanta Ga., 0300 GMT
(a) Type F_{850}
(b) Type C_{850}
(c) Type A_{850}
(d) Type F_{700}
(e) Type C_{700}
(f) Type A_{700}

FIGURE 2.—Diagrams showing probability of "thunderstorm days" for three classes of circulation at 850 and at 700 mb. from five seasons of data. The observed weather, "thunderstorm day" (●) or "no-thunderstorm day" (○), is plotted as a function of the mixing ratio at 850 and 700 mb. The solid lines represent isopleths of frequency of thunderstorm occurrence and define variables X_1 and X_2 which are plotted as coordinates in figure 3.

to the circulation (flat (F), cyclonic (C), or anticyclonic (A)) at the 850-mb. level. Next, these same data were plotted on one of three other diagrams, figure 2d, 2e, or 2f, depending upon the 700-mb. circulation. Then isopleths of equal frequency of thunderstorm occurrence were drawn on each of these six diagrams. Thus, two probabilities, X_1 and X_2 of the occurrence of thunderstorms were obtained for each date from these humidity and circulation data. These probabilities were combined into another scatter diagram, shown in figure 3, and probability lines again drawn, resulting in one probability, Y_1, which depends upon the humidity and circulation at both the 850- and 700-mb. levels.

Six other scatter diagrams, figure 4, were utilized to combine the measure of stability ($T_{850}-T_{700}$) and the 24-hour change in stability (ΔT_{24}). The procedure was the same as that used in the case of mixing ratios. The stability measure was plotted against the stability change on one of these diagrams, figure 4a, 4b, or 4c, depending upon the circulation at 850 mb. These same data were plotted on figure 4d, 4e, or 4f, according to the circulation at 700 mb. Isopleths of equal frequency of thunderstorms as related to these variables were drawn on these diagrams and resulted in two more probabilities, X_3 and X_4, for each date. These two probabilities were combined into the single diagram shown in figure 5 and resulted in one probability, Y_2, which depends upon the stability, change in stability, and circulation at 850 and 700 mb. Finally, this probability (Y_2) from figure 5 was combined with the probability based upon humidity and circulation (Y_1) from figure 3 into the forecast diagram shown in figure 6 which gave a final probability, Z.

VERIFICATION OF METHOD

Figure 6 was used to determine a "forecast" for the Atlanta area. Using a probability of 50 percent or greater as a forecast of a "thunderstorm day", the skill

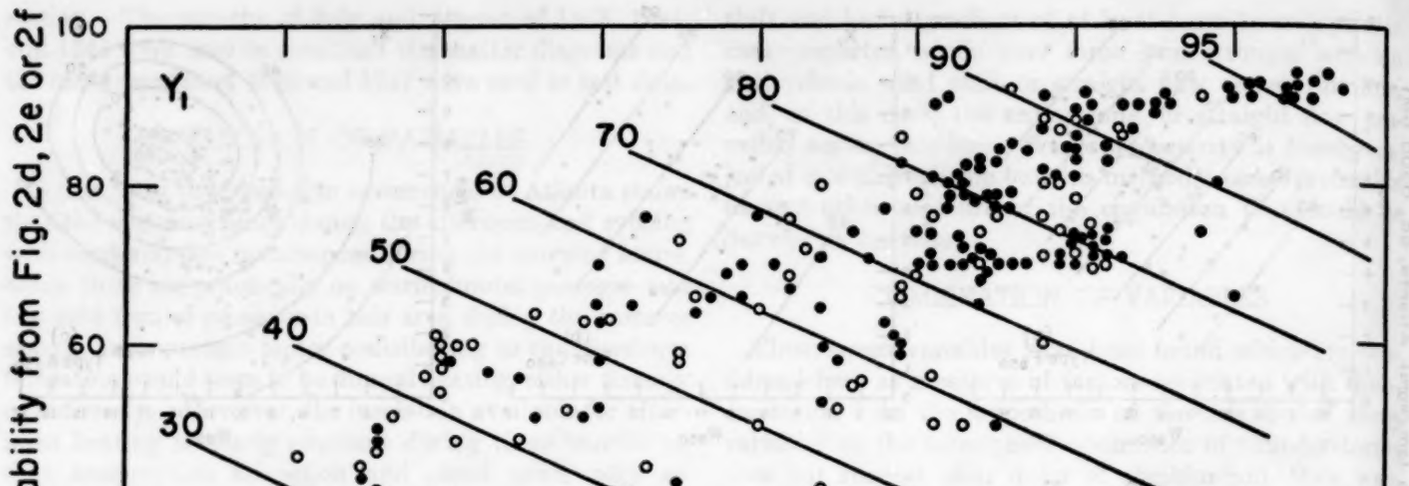

FIGURE 3.—Diagram showing probability of "thunderstorm days" as a function of X_1 (from fig. 2a, 2b, or 2c) and X_2 (from fig. 2d, 2e, or 2f). The solid lines represent isopleths of frequency of thunderstorm occurrence and define a variable Y_1, which is plotted as the abscissa in figure 6.

TABLE 1.—*Contingency tables showing verification of objective forecasts based on (a) dependent data, (b) independent data, and (c) data for a period of actual use*

(a) Dependent data 1943, 1944, 1945

		Forecast: Thunderstorm	Forecast: No thunderstorm	Total	
Observed	Thunderstorm	73	6	79	Skill score: .62
	No thunderstorm	24	55	79	Percent correct: 81
	Total	97	61	158	

(b) Independent data 1946, 1947

		Forecast: Thunderstorm	Forecast: No thunderstorm	Total	
Observed	Thunderstorm	54	8	62	Skill score: .56
	No thunderstorm	19	43	62	Percent correct: 78
	Total	73	51	124	

(c) Actual use data 1948, 1949, 1950, 1951

		Forecast: Thunderstorm	Forecast: No thunderstorm	Total	
Observed	Thunderstorm	126	13	139	Skill score: .53
	No thunderstorm	43	66	109	Percent correct: 77
	Total	169	79	248	

score [1] for dependent data was .62 with 81 percent of the cases correctly forecast. The seasons 1946 and 1947 were used to test this forecasting aid as a method in itself. Again using a probability of 50 percent or greater as a forecast of a "thunderstorm day", the skill score was .56 with 78 percent of the cases correctly forecast. This aid was in actual use during the 1948, 1949, 1950, and 1951 seasons and the skill score for these four seasons was .53 with 77 percent of the cases correctly forecast. Contingency tables showing these verification results are given in table 1.

A direct comparison between the "forecasts" from this aid when tested as a method and the official forecasts for the Atlanta area is not entirely valid as there are differences in area and, further, the official forecasts for Atlanta do not express a categorical forecast of thunderstorms or no-thunderstorms. However, a subjective verification of the official forecasts suggests little real differences in the overall accuracy between the forecasts by conventional methods and those from this aid when considered as a method.

[1] The skill score, S, as used here is defined as

$$S=\frac{C-E}{T-E}$$

where C=number of correct forecasts, E=number of forecasts expected to be correct due to chance, and T=total number of forecasts. The value of E for forecasts of "thunderstorm days" and "no-thunderstorms" is given by

$$E=PF+N(1-F)$$

where P=number of forecasts of "thunderstorm days" during the period covered by the forecasts, N=number of forecasts of "no-thunderstorms" during this period, F=relative frequency of occurrence of thunderstorm days during this period.

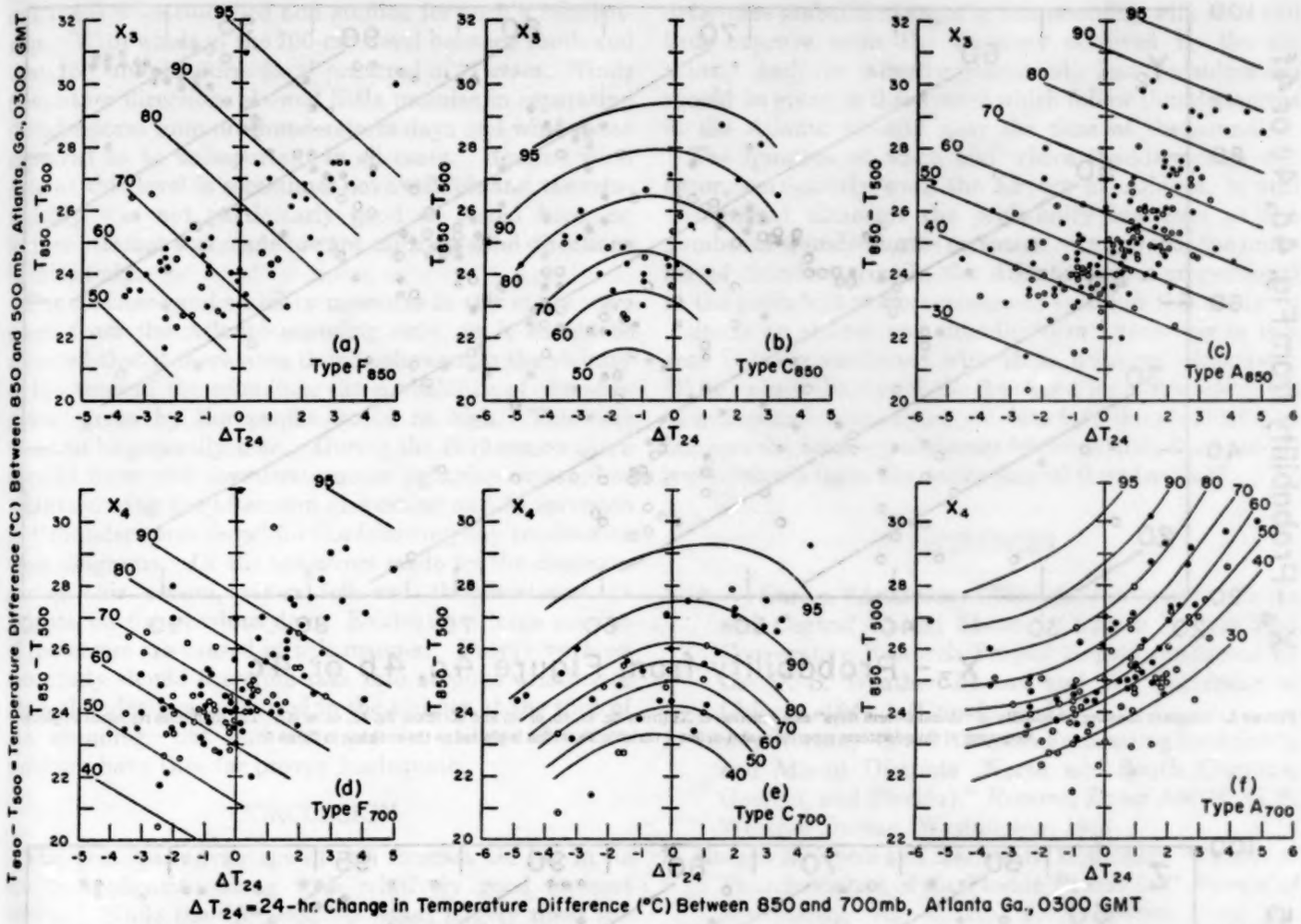
X3
X4
(a) Type F850
(b) Type C850
(c) Type A850
(d) Type F700
(e) Type C700
(f) Type A700
T850 − T500 = Temperature Difference (°C) Between 850 and 500 mb, Atlanta, Ga., 0300 GMT
ΔT24 = 24-hr. Change in Temperature Difference (°C) Between 850 and 700mb, Atlanta Ga., 0300 GMT

FIGURE 4.—Diagram showing probability of "thunderstorm days" for three classes of circulation at 850 and 700 mb. from five seasons of data. The observed weather is plotted as a function of the temperature difference between 850 and 500 mb. and the 24-hour change in this temperature difference. The solid lines represent isopleths of frequency of thunderstorm occurrence and define variables X_3 and X_4 which are plotted as coordinates in figure 5.

The original scatter diagrams contained data from only three seasons. Then after the independent data had been used in checking this study, these data were added to the diagrams and they were reanalyzed. However, there were no important differences either in the analysis or the results, so the diagrams shown here and those in use at Atlanta contain five seasons of data. The accuracy during the 1948, 1949, 1950, and 1951 seasons was not appreciably different from the independent data so it seems that any increase in the sample size would not materially affect the results of this study.

FURTHER INVESTIGATIONS

Some other measures of the circulation and humidity values were attempted but the results were not encouraging. An indication of the sea level pressure distribution might be the position of the Bermuda High, or a cell from this High that has moved westward. Two months of data (July and August, 1943) were used and a thunderstorm or no-thunderstorm symbol plotted on a map at the apparent center of any sea level High over the southeastern United States or as far eastward as Bermuda. There was no marked differentiation between the thunderstorm or no-thunderstorm cases.

Presumably the moisture which will move over a station or an area is of more importance than the original humidity values. An attempt was made to estimate the moisture values upstream that would be advected over the Atlanta area. But, as most forecasters in this area know, moisture values on the constant pressure charts do not move in an orderly fashion over this area during the summer season. Presumably this difficulty is largely due to convection. Advective moisture values as used here apparently contribute nothing more and also introduce other problems and so were not further considered.

As it might be expected that the direction of the wind flow aloft would have some relation to thunderstorm occurrences, two seasons of data (July and August, 1943

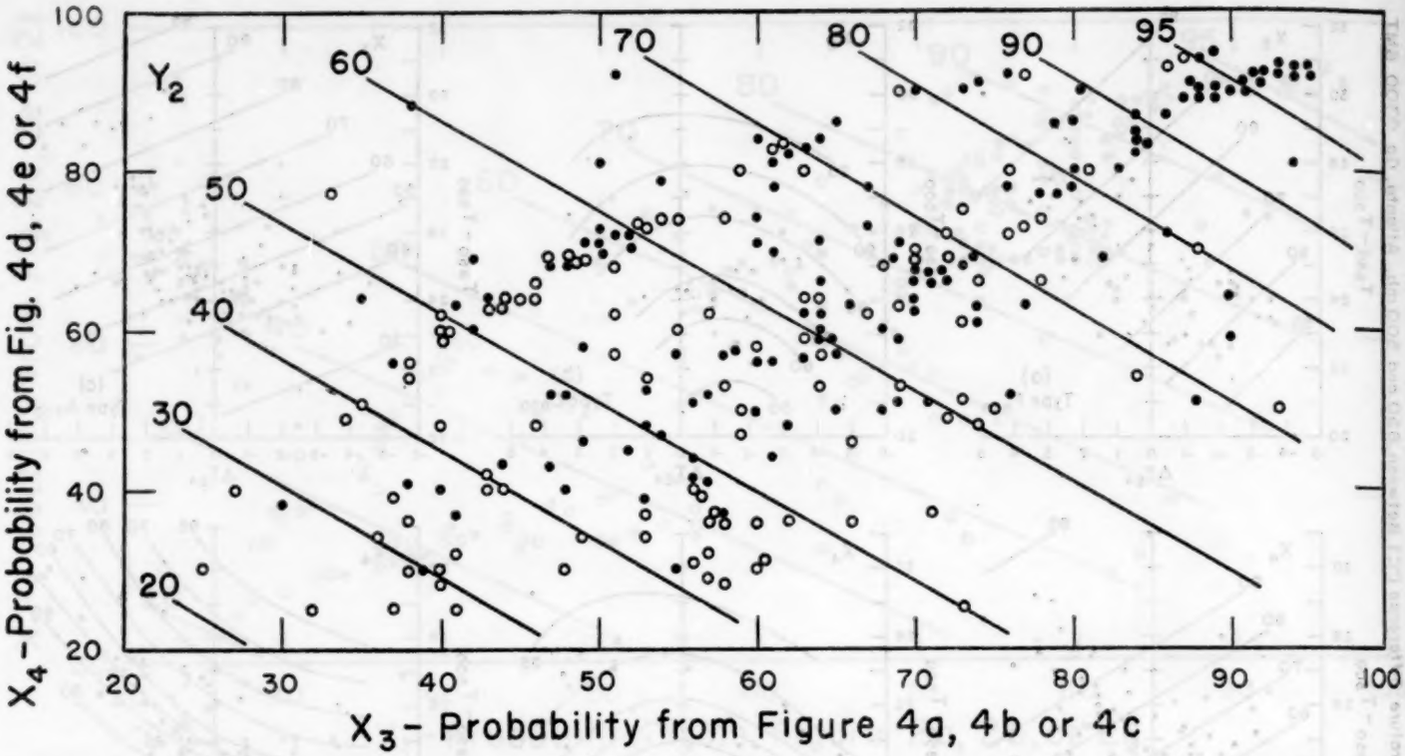

FIGURE 5.—Diagram showing probability of "thunderstorm days" as a function of X_3 (from fig. 4a, 4b, or 4c) and X_4 (from fig. 4d, 4e, or 4f). The solid lines represent isopleths of frequency of thunderstorm occurrence and define a variable Y_2, which is plotted as the ordinate in figure 6.

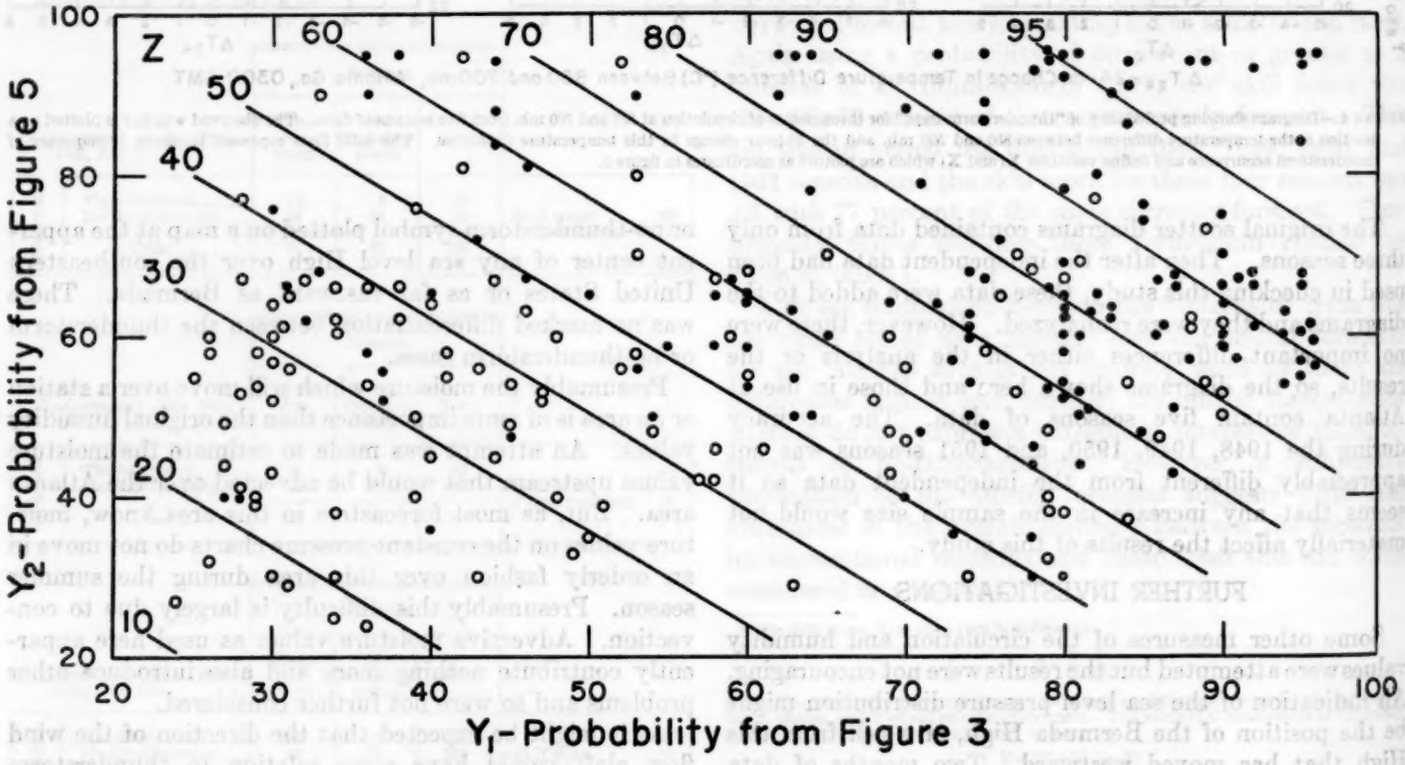

FIGURE 6.—Diagram showing probability (Z) of "thunderstorm days" as a function of Y_1 (from fig. 3) and Y_2 (from fig. 5). The 50 percent probability line was used to determine a categorical "forecast" for the Atlanta area.

and 1945) were compiled and studied for such a relationship. With winds at the 700-mb. level between south and west, 15 "thunderstorm days" occurred in 17 cases. Winds from other directions showed little promise in separating thunderstorm from no-thunderstorm days and wind speed appeared to be unimportant in all cases. Because wind data at this level is sometimes not available and the relationship was not particularly good as tested here, no further attempt was made toward utilizing wind directions in this study.

The moisture and stability measures in this study were taken from the Atlanta sounding only, so it should be expected that if there were thundershowers in the vicinity at the time of the sounding, the probability of thunderstorms given by the graphs would be high. This was found to be generally true. During the 1949 season there were 34 days with thunderstorms or lightning reported at Atlanta during the afternoon or evening and 31 forecasts for "thunderstorm days" for the following day resulted on these diagrams. Of the ten errors made by the diagrams during this season, seven followed thunderstorms at Atlanta on the previous day. Evidently a large portion of the errors are caused in this manner. Future work on this study should therefore take into account whether or not a thunderstorm occurred in the vicinity at the time of the sounding, but our attempts to utilize advective moisture have thus far proven inadequate.

CONCLUSION

The principal advantage of this forecast aid lies in its simple application along with relatively good forecast results. While the "forecast" is based largely upon the sounding at Atlanta, the forecaster is in a position to determine probable changes in this sounding with time and thus improve upon the accuracy achieved by the aid alone. And, as already suggested, less consideration should be given to those cases which follow thunderstorms in the Atlanta vicinity near the time of the sounding.

The question of when and where thunderstorms will occur, particularly over the airport at Atlanta, is still unanswered although the probability increases as the number of thunderstorms increases. In general, the number of thunderstorms in the Atlanta area is proportional to the probability of occurrence as found in this study.

Study on shower and thunderstorm forecasting in this area is being continued with these principal objectives: (1) to reduce the size of the area used for verification; (2) to incorporate more upper air data into the study; (3) to improve the accuracy of shower forecasts with, if necessary, less emphasis upon the occurrence of thunder itself.

REFERENCES

1. A. V. Carlin, "Analyses of Thunderstorms in the South and Central United States," Chapter I, Part 2 of Cooperative Research Project Report conducted by the U. S. Weather Bureau and the University of Chicago, 1944. (Unpublished)
2. Grady Norton, "Some Notes on Forecasting for Atlanta and Miami Districts (North and South Carolina, Georgia, and Florida)," *Research Paper No. 15*, U. S. Weather Bureau, Washington, 1944.
3. Horace R. Byers and Harriet R. Rodebush, "Causes of Thunderstorms of the Florida Peninsula," *Journal of Meteorology*, vol. 5, No. 6, December 1948, pp. 275–280.

THE WEATHER AND CIRCULATION OF APRIL 1952[1]

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On Duty with Extended Forecast Section, U.S. Weather Bureau, Washington, D. C.

The circulation patterns of April 1952 were rather complex at both 700 mb. (fig. 1) and sea level (Chart XI). At both levels a deep mean trough extended from the Alaskan Arctic to the southeast Pacific, with greatest negative anomalies centered in the Gulf of Alaska. The low latitude trough observed just south of California may be considered as an eastward extension of the basic trough in the Gulf of Alaska. Thus, this trough tilted strongly from northwest to southeast. This was associated with a splitting of the westerlies and a southward transport of westerly momentum throughout the eastern Pacific. In eastern North America, on the other hand, the northern and southern streams of westerlies converged into a mean trough with strong tilt from northeast to southwest and extending from Florida to Iceland. The wave length between these two troughs, while long at high latitudes, was relatively short at low latitudes. An extensive ridge with positive 700-mb. height anomalies of 220 feet was located in central Canada, but the counterpart of the ridge in the southern United States was relatively weak and contracted.

[1] See charts I–XV following page 76 for analyzed climatological data for the month.

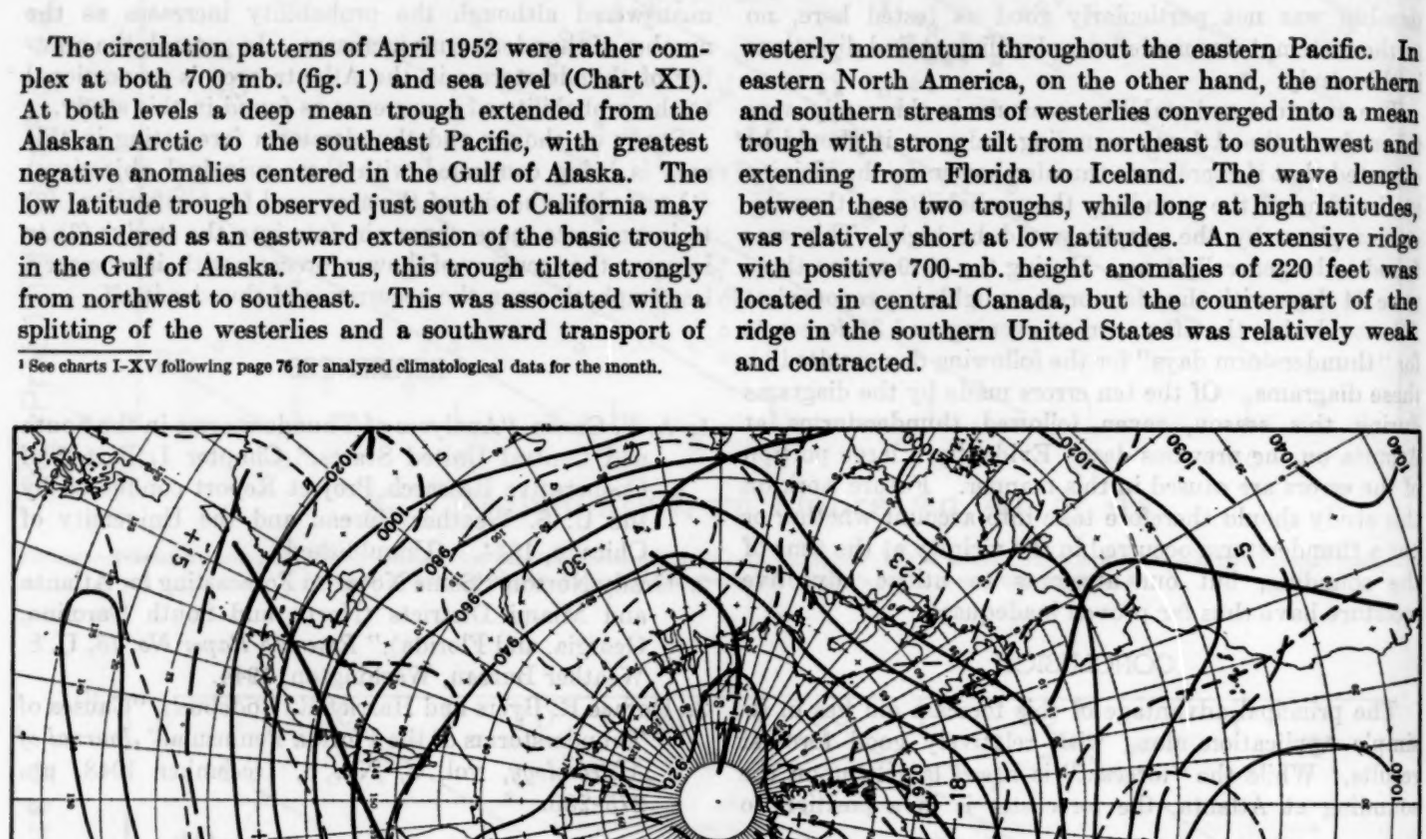

FIGURE 1.—Mean 700-mb. chart for 30-day period April 1–30, 1952. Contours at 200-ft. intervals are shown by solid lines, intermediate contours by lines with long dashes, and 700-mb. height departures from normal at 100-ft. intervals by lines with short dashes with the zero isopleths heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines.

Some of the more striking features of the month's circulation are illustrated in figure 2, showing the geographical distribution of mean 700-mb. geostrophic wind speed. The band of strongest westerlies (jet) throughout the central Pacific was concentrated between 40°N. and 45°N. latitude with a maximum monthly average of 20 m.p.s. This current underwent considerable diffluence or spreading in the eastern Pacific, with one portion proceeding northward through Canada and the other southward along the southern border of the United States. This split in the westerlies resulted in very weak gradients at middle latitudes of the United States as shown by the large distance between the 10,000-ft. and 10,200-ft. contours in figure 1. The two jet streams at 700 mb. converged in the area of confluence ahead of the mean trough in eastern North America. Here the westerlies again became unified into a very strong, concentrated band with maximum values of 17 m.p.s. at 40°N. in the western Atlantic. Farther eastward the westerlies again split, one portion going northward through Scandinavia and the other southward into Africa. Thus in the Western Hemisphere during April the unified wind belt found over each ocean split into two distinct and widely separated bands over the continents.

The characteristics of the mean circulation and wind portrayed in figures 1 and 2 are reflected in the observed tracks of individual daily cyclones (Chart X). The principal cyclone tracks are delineated in figure 3. In the Pacific the cyclones were quite concentrated in a track extending northeastward from the Japanese Islands to the Gulf of Alaska. The principal cyclone track, like the 700-mb. jet stream, split in North America, one branch passing across northern Canada and the other across the central United States. These branches rejoined just east of the mean trough along the east coast of North America. The maximum concentration of cyclones was near Newfoundland. A comparison of figures 2 and 3 shows that the principal cyclone tracks were slightly to the north of the strongest belt of westerly winds, in the regions of strong cyclonic shear [1]. Storms were relatively scarce throughout the northwestern and north central sectors of the United States, in the area of anticyclonic shear to the south of the strongest westerly wind belt.

The observed precipitation (Chart III) was above normal in a band extending from the southwestern United States northeastward to the North Atlantic States. This band of heavy precipitation corresponds to the area of maximum cyclone frequency shown in figure 3. Similarly, areas of subnormal precipitation in the Northwest, Southeast, and Northern Plains correspond to the areas where cyclones were scarce or absent. Despite the light precipitation observed in the Northern Plains, some of the worst floods of record were observed in the Missouri and upper Mississippi Valleys. These flood conditions were brought about chiefly by heavy snow melt and rapid ice breakup in the northern States at the beginning of April.

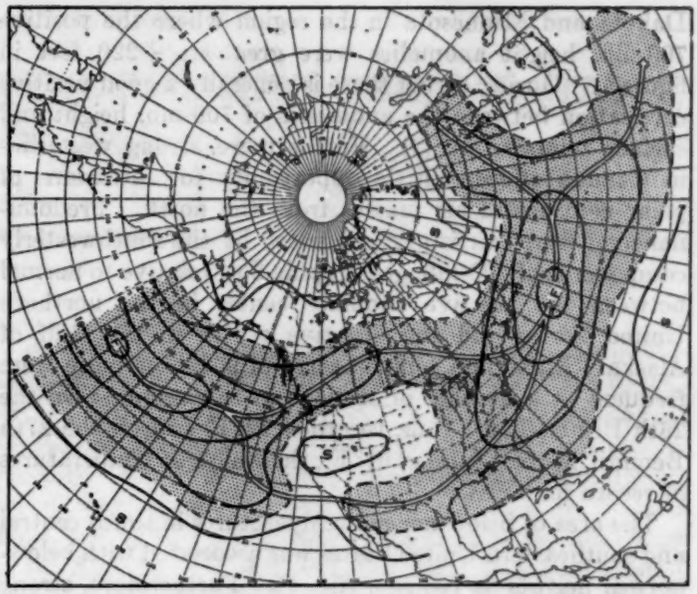

FIGURE 2.—Mean geostrophic (total horizontal) wind speed at 700-mb. for the 30-day period April 1-30, 1952. Solid lines are isotachs at intervals of 4 m/sec. with intermediate values dashed. Open double-arrowed lines delineate the axes of maximum wind speed (jets). Areas with speed in excess of 6 m/sec. are stippled. Centers of maximum and minimum wind speed are labeled "F" and "S" respectively.

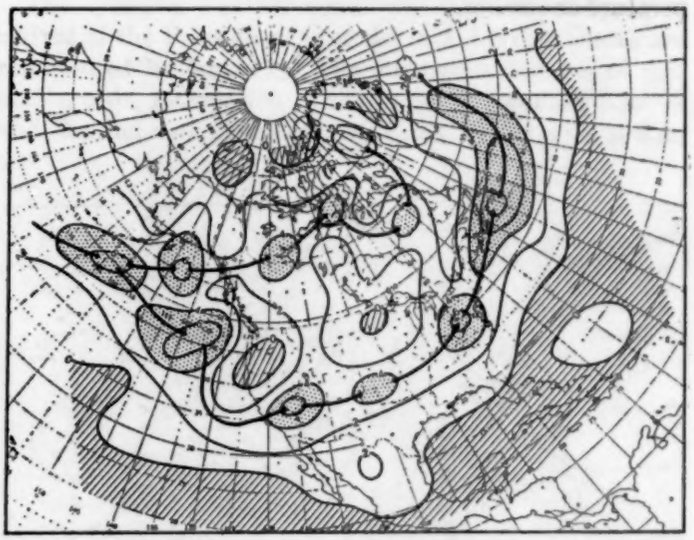

FIGURE 3.—Geographical frequency of tracks of cyclones observed during month of April 1952 within approximately equal-area boxes of size 5 middle-latitude-degrees of longitude by 5° of latitude. The isopleths are drawn at intervals of 2. Areas with more than 4 cyclone passages are stippled, and areas of zero frequency are hatched. The principal cyclone tracks are indicated by double-arrowed lines, which are broken in regions of maximum frequency. All data obtained from Chart X.

The anomalies of surface temperature given in Chart I-B show that relatively warm weather prevailed over western and northern portions of the United States, but below-normal temperatures were observed in south central and southeastern sections. The most extreme positive temperature departures (over 10° F.) were found in North

Dakota and Minnesota in the region where the positive 700-mb. height anomalies were greatest, +220 feet in figure 1. During spring there is generally a good positive correlation between the anomalies of 700-mb. height and surface temperature [2]. Furthermore, strong westerlies in Canada afforded little opportunity for intrusions of polar continental air masses from the north. Predominance of warm air is also suggested by the southwesterly components of 700-mb. geostrophic flow relative to normal between the positive anomaly center in the northern United States and the negative center in the Gulf of Alaska. Maximum temperatures of 90°F. or more were frequent at a number of stations in this sector. On the 26th Bismarck, N. Dak. recorded 92°F. and on the 27th Bemidji, Minn. recorded 91°F., their highest temperatures of record for April.

The area of below-normal temperatures in south central and southeastern United States was associated with below-normal heights at 700 mb. (fig. 1). Furthermore, strong northerly components of flow (relative to normal) are shown at sea level (Chart XI inset) between the positive anomaly center in central United States and the negative one at Hatteras. Such northerly wind components are frequently associated with below-normal surface temperature anomalies.

The circulation patterns of April 1952 did not exhibit the extreme anomalies of the previous month [3]. In many regions the April circulation was markedly different, almost opposite in phase, from that observed during March. This was particularly true in eastern portions of the United States and Pacific, where mean ridges during March were replaced by mean troughs during April. As a result, the pattern of surface temperature anomaly in the United States was strikingly different during the 2 months (compare Chart I-B of *Monthly Weather Review* for March and April 1952).

REFERENCES

1. W. H. Klein, "The Weather and Circulation of December 1951", *Monthly Weather Review*, vol. 79, No. 12, December 1951, pp. 218-221.
2. D. E. Martin and W. G. Leight, "Objective Temperature Estimates from Mean Circulation Patterns", *Monthly Weather Review*, vol. 77, No. 10, October 1949, pp. 275-283.
3. D. E. Martin, "The Weather and Circulation of March 1952", *Monthly Weather Review*, vol. 80, No. 3, March 1952, pp. 47-49.

THE PROLONGED RAIN PERIOD OVER THE ATLANTIC COASTAL STATES, APRIL 23–29, 1952

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INTRODUCTION

On April 23, 1952, a continental Polar air mass moved eastward and southeastward across the Great Lakes region toward the mid-Atlantic and New England States. The associated cold front, which had been moving eastward with a nearly north-south alignment until this date, accelerated markedly north of the United States-Canadian border and to a lesser extent in portions of Oklahoma and Texas. As a result of the different rates of progression, the cold front was distorted into the form of a wave over Missouri. This wave structure moved slowly eastward and southeastward during the following three days bringing rain to the eastern United States. After the 3d day, a new low center developed over Georgia, within the major trough which had been a part of the weather sequence since the 23d. A new rain area moved northeastward along the Atlantic coast to Virginia and then moved eastward in association with the slow moving wave.

Just what this weather sequence meant to the public is illustrated by the rainfall records from the Washington, D. C., City Office. On April 23, a shower at 3:00 p. m. (EST) marked the start of 137 hours of almost continuous rainfall. Within this period there were 133 hours during which rain was reported during some part, or all, of each hour, and of these, 114 were consecutive hours from 7:00 p. m., April 23 to 1:00 p. m., April 28. The total rainfall recorded at the City Office during the 137 hours amounted to 5.28 in. The rainfall finally ended over the eastern States on the 29th.

SURFACE FRONTAL ACTIVITY AND THE 700-MB. FLOW

The synoptic weather conditions 24 hours before the arrival of the Polar front over the mid-Atlantic States are represented by figure 1. The important features of this map are the retardation of the front over eastern Kansas and the indirect evidence, suggested by its orientation,

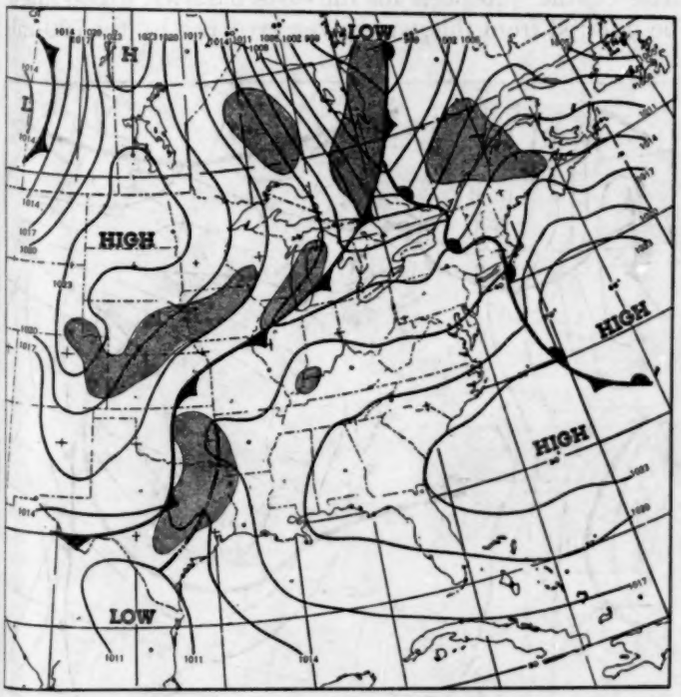

FIGURE 1.—Surface chart 1830 GMT, April 22, 1952. Shading indicates areas of active precipitation.

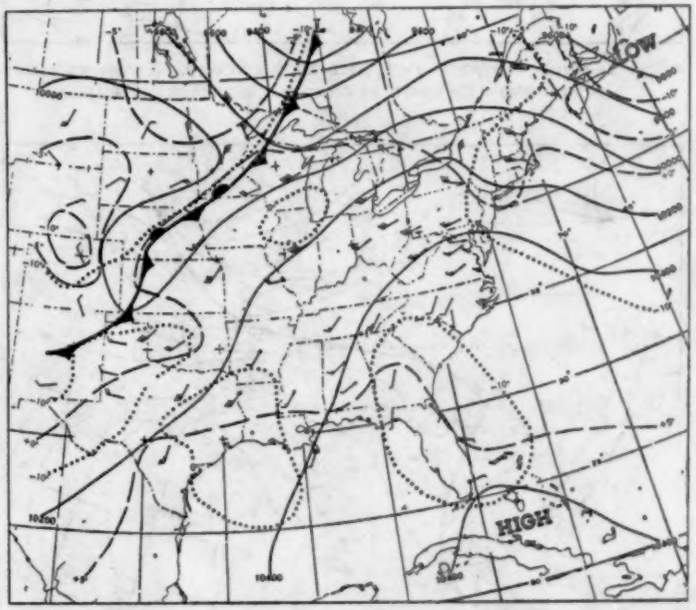

FIGURE 2.—700-mb. chart, 1500 GMT, April 22, 1952. Contours (solid lines) at intervals of 200 geopotential feet. Isotherms (dashed lines) at intervals of 5° C. and dew point isotherms (dotted lines) at intervals of 10° C. Barbs on wind arrows are for speeds in knots (pennant=50 knots, full barb=10 knots).

that the northern end of the cold front was moving eastward more rapidly than the remaining portion in the United States. The development of rain areas and the retardation of the front presaged slow moving weather conditions.

The surface rain areas of figure 1 were beneath the area of moist air aloft which occupied the East Texas-Oklahoma-Arkansas region and the region between the surface cold front and the 700-mb. front (fig. 2), from Oklahoma northeastward toward James Bay, Canada. A comparison of figures 1 and 2 shows the 700-mb. winds in the moist air were parallel to the surface front. This is generally regarded as favorable for the production of precipitation. Moreover, these two charts studied together give valuable information with respect to the probable 24-hour progress of the surface front. In the 700-mb. air flow above and to the west of the surface cold front there were two strong westerly currents, one generally north of the United States-Canadian border, a second over the southern portion of the cold front (Texas Panhandle). Between these two streams the winds over the Plains States were relatively weak.

As a qualitative estimate the northwest winds over southern Canada were blowing at about twice the speed of the west winds of the southern zone. The west wind component of the northern stream was about 28 knots, of the southern stream about 15 knots. No definite statement can be made about the wind components along the section of the upper cold front from southwest Kansas northeastward to Minnesota, although, it would appear that a small eastward component had existed. These estimates were indicative of the frontal movement during the next 24 hours.

The 1830 GMT map for April 23 (fig. 3) showed that the indicated changes in the frontal position had occurred. Surface data alone suggested that the cold front would continue to move eastward along the northern border but would continue to hold back in the middle of the country. The weather prospects for the eastern States, which might be inferred from this, were given credence by the 700-mb.

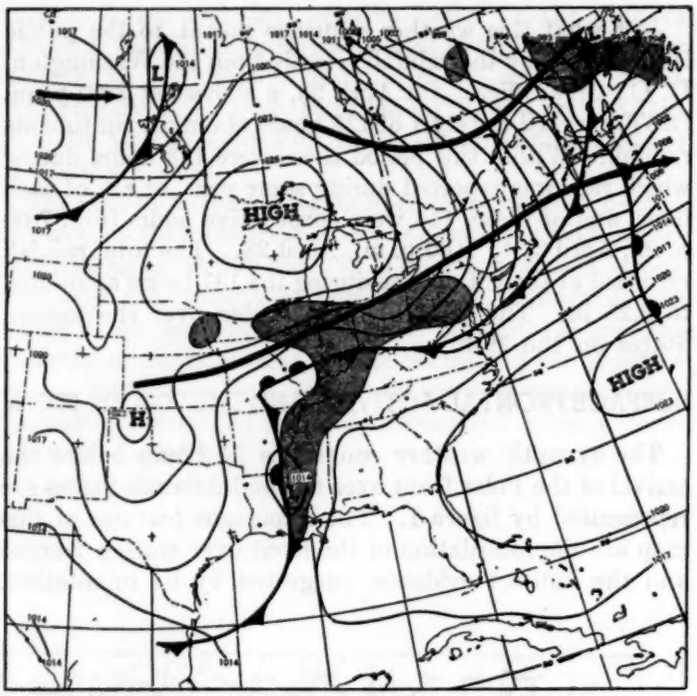

FIGURE 3.—Surface chart, 1830 GMT, April 23, 1952. Heavy, black arrows indicate superposition of the 300-mb. jet stream axis upon the surface chart.

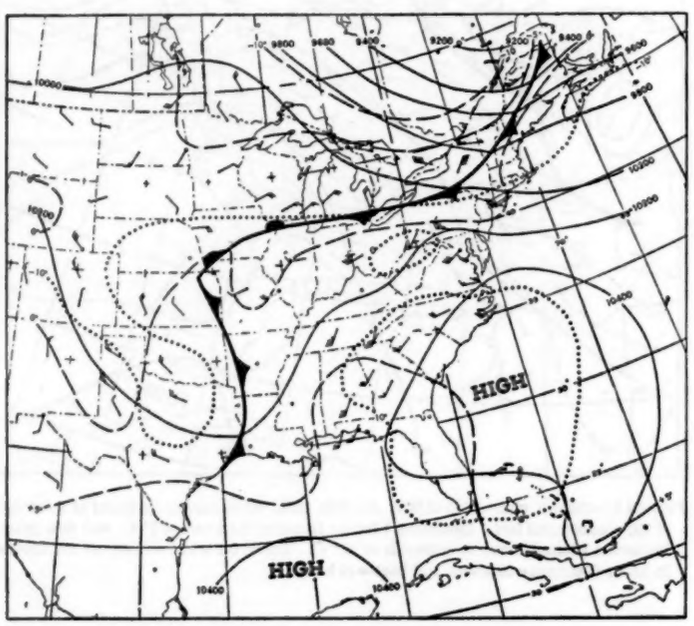

FIGURE 4.—700-mb. chart, 1500 GMT, April 23, 1952.

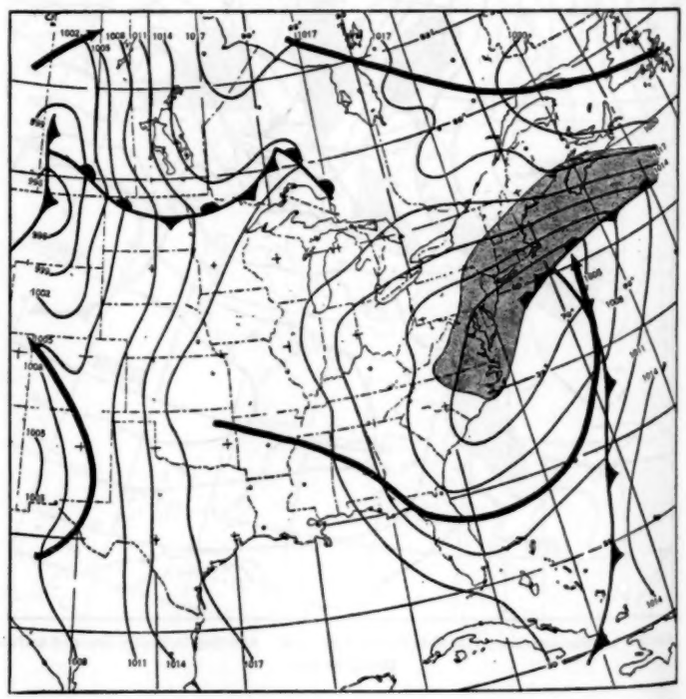

FIGURE 5.—Surface chart 1830 GMT, April 28, 1952. Heavy, black arrows indicate superposition of the 300-mb. jet stream axis upon the surface chart.

flow at 1500 GMT on the 23d (fig. 4). The flow indicated rapid eastward motion for the section of the cold front extending north of the southern border of New York State, slow eastward movement for the southernmost segment of the cold front, and, in comparison to the previous day, a slightly more rapid movement for the wave. This was the sequence of events during the rain period.

A wave that was at Augusta, Ga., at 1830 GMT on the 26th moved to Norfolk, Va., and deepened 5 mb. in the following 24 hours (fig. 5). In the 24 hours after this map, rain fell along the coastal plain from Maine to South Carolina, although no station in this area reported a 24-hour total as large as 1 in. The area of rain totals exceeding ½ in. included Massachusetts, portions of New Hampshire, Vermont, and the southwestern tip of Maine. On previous days totals of over ½ in. covered many States as, for example, in the 24-hour period ending April 26 (fig. 6).

Figure 7, which shows the essential features of the 700-mb. flow at 1500 GMT on April 28, the last day of widespread rainfall, provides a clue as to the manner in which the moisture supply reached the rain area. During the first half of the rain spell, on the east side of the 700-mb. trough (fig. 4), moist air moved northward in the Mississippi Valley region as a returning anticyclonic flow which spread fanwise over the Lakes region and the northern half of the Atlantic coast area. As the upper trough moved slowly eastward and developed more cyclonic characteristics (fig. 7), the Atlantic coast region came under the

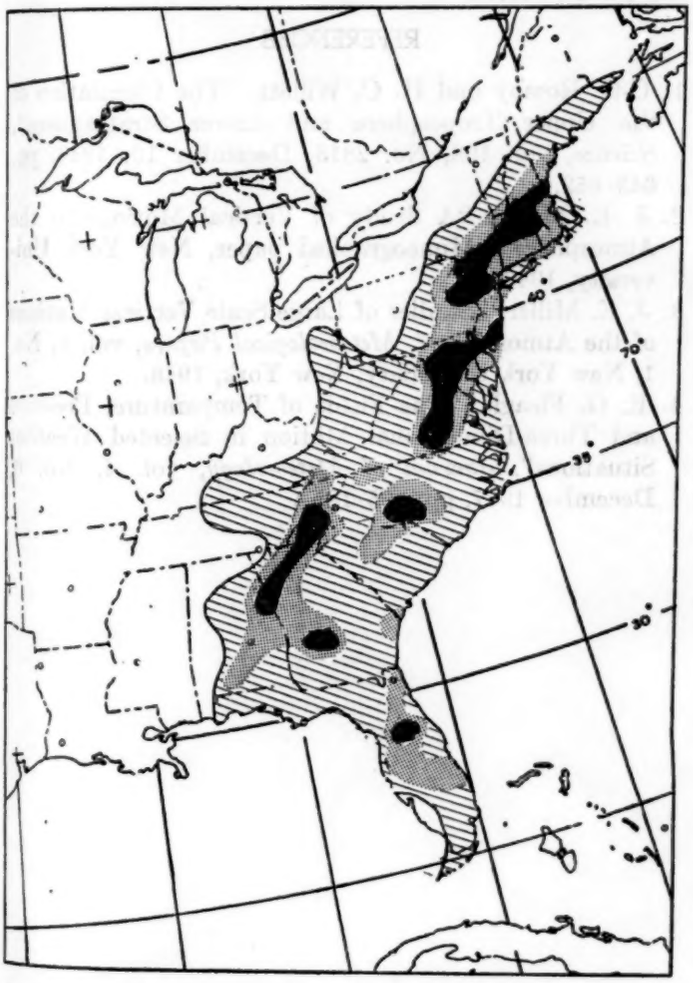

FIGURE 6.—Precipitation chart for 24 hours ending 1230 GMT, April 26, 1952. Slant line indicates Trace to 0.5 in., stipple indicates 0.5 in. to 1 in., and black indicates 1 in. or more.

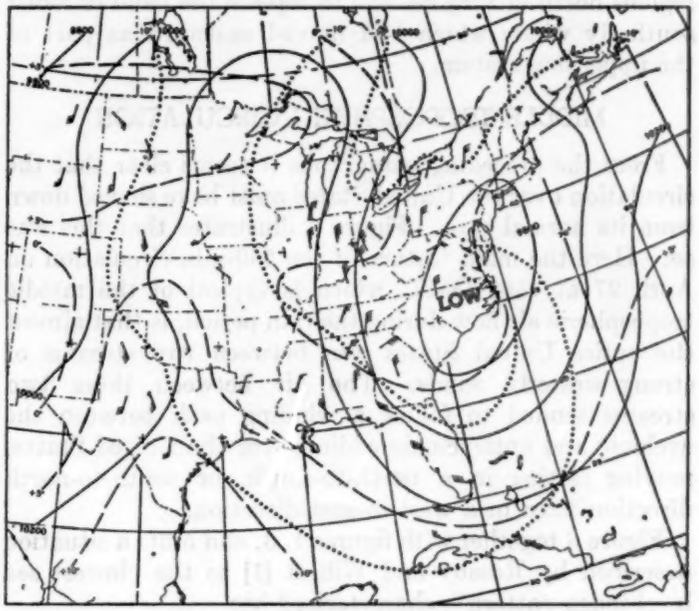

FIGURE 7.—700-mb. chart, 1500 GMT, April 28, 1952.

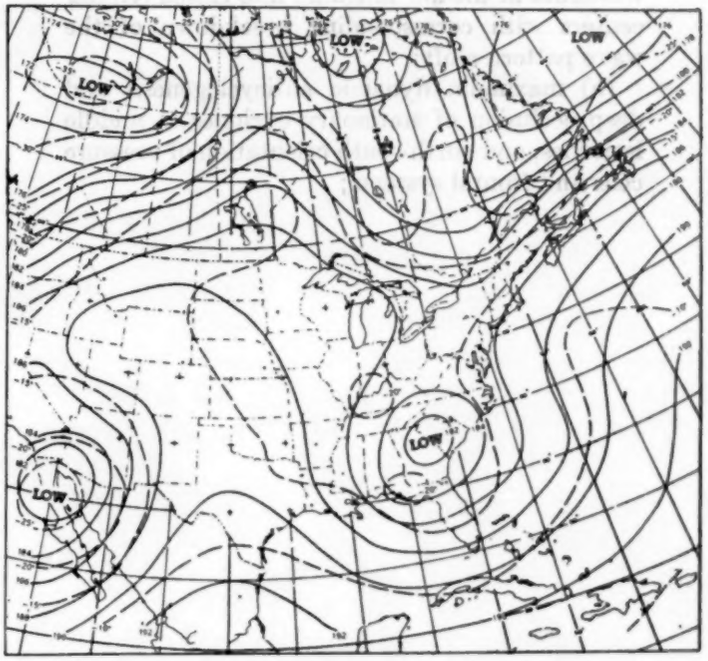

FIGURE 8.—500-mb. chart, 1500 GMT, April 27, 1952. Contours (solid lines) at intervals of 200 geopotential feet. Isotherms (dotted lines) at intervals of 5° C. Barbs on wind arrows are for speeds in knots (pennant=50 knots, full barb=10 knots).

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influence of the circulation of the upper level Low. Easterly winds on the north side of the Low and southerly winds along the coast brought moist air inland from the South Atlantic coastal waters. It can be seen from figure 5 that these winds were moving upslope over cold east-to-northeast surface winds.

By 1500 GMT on the 29th the 700-mb. Low had moved to the Delaware Capes before changing course to an eastward drift. This permitted the dry air from the north-to-northeast to move into the Atlantic coastal regions north of Virginia and to replace the band of moist southerly winds which had moved eastward as part of the upper low system.

MIDDLE TROPOSPHERIC CIRCULATION

From the preceding paragraphs it seems clear that the circulation over the United States must have slowed down from its normal rate. Figure 8 illustrates that this was so. Here the main feature of the 500-mb. circulation on April 27 at 1500 GMT, which is typical of the middle tropospheric air flow during the rain period, is that almost the entire United States was between two streams of strong westerly winds. The air between these two streams tended to follow a winding path between the cyclonic and anticyclonic eddies, over the United States, moving farther in a north-to-south, or south-to-north direction than in a west-to-east direction.

Figure 8 together with figures 1, 3, and 5 fits a situation described by Rossby and Willett [1] as the "lowest sea level index pattern", characterized by:

> "(a) complete breakup of the sea-level zonal westerlies in the low latitudes into closed cellular centers with corresponding breakdown of the wave pattern aloft;
>
> (b) maximum dynamic anticyclogenesis and deep occlusion of stationary cyclones in middle latitudes, and north-south orientation of pressure cells and frontal systems;
>
> (c) maximum east-west rather than north-south air mass temperature contrasts; and
>
> (d) development of strong troughs and ridges in the circumpolar vortex and jet stream, with cutting off of warm Highs in the higher latitudes and cold cyclones in the lower latitudes."

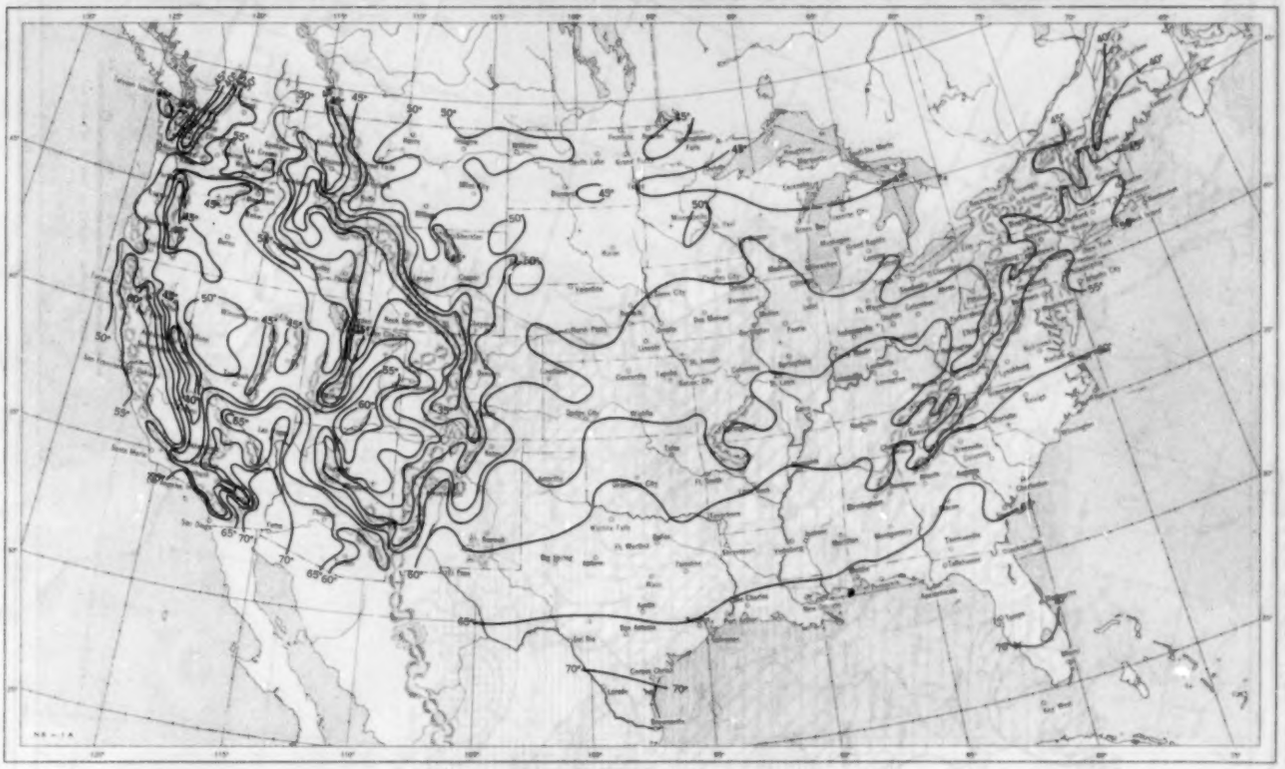
The surface precipitation areas were east and northeast of the 500-mb. Low (fig. 8) centered over South Carolina. This spatial distribution of precipitation with respect to the upper Low was about the same throughout the rain period. Miller [2, 3] and Fleagle [4] in a study of vertical motions in upper troughs and associated surface cyclones found there is usually descending motion on the west side of an upper trough and ascending motion on the east side. Further, they say low level divergence and upper level convergence on the west side contrast with low level convergence and upper level divergence on the east side of the upper trough. So, in this case, the vertical motions described seem to account for the rainfall pattern along the eastern coastal sections and the contrasting lack of precipitation over the central portion of the United States.

REFERENCES

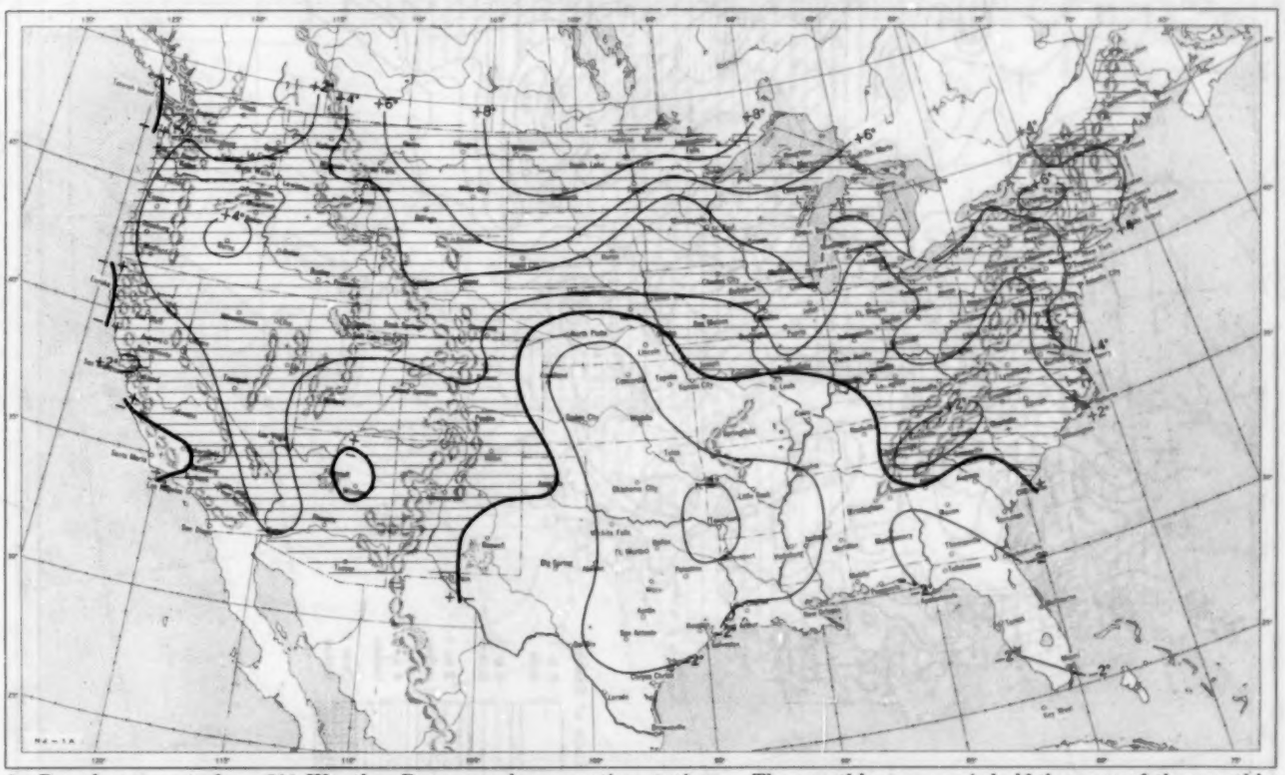
1. C-G. Rossby and H. C. Willett, "The Circulation of the Upper Troposphere and Lower Stratosphere", *Science*, vol. 108, No. 2815, December 10, 1948, pp. 643-652.
2. J. E. Miller, "A Study of Vertical Motions in the Atmosphere", Mimeographed paper, New York University, 1946.
3. J. E. Miller, "Studies of Large Scale Vertical Motions of the Atmosphere", *Meteorological Papers*, vol. 1, No. 1, New York University, New York, 1948.
4. R. G. Fleagle, "The Fields of Temperature, Pressure and Three-Dimensional Motion in Selected Weather Situations", *Journal of Meteorology*, vol. 4, No. 6, December 1947, pp. 165-185.

U. S. GOVERNMENT PRINTING OFFICE: 1952

Chart I. A. Average Temperature (°F.) at Surface, April 1952.

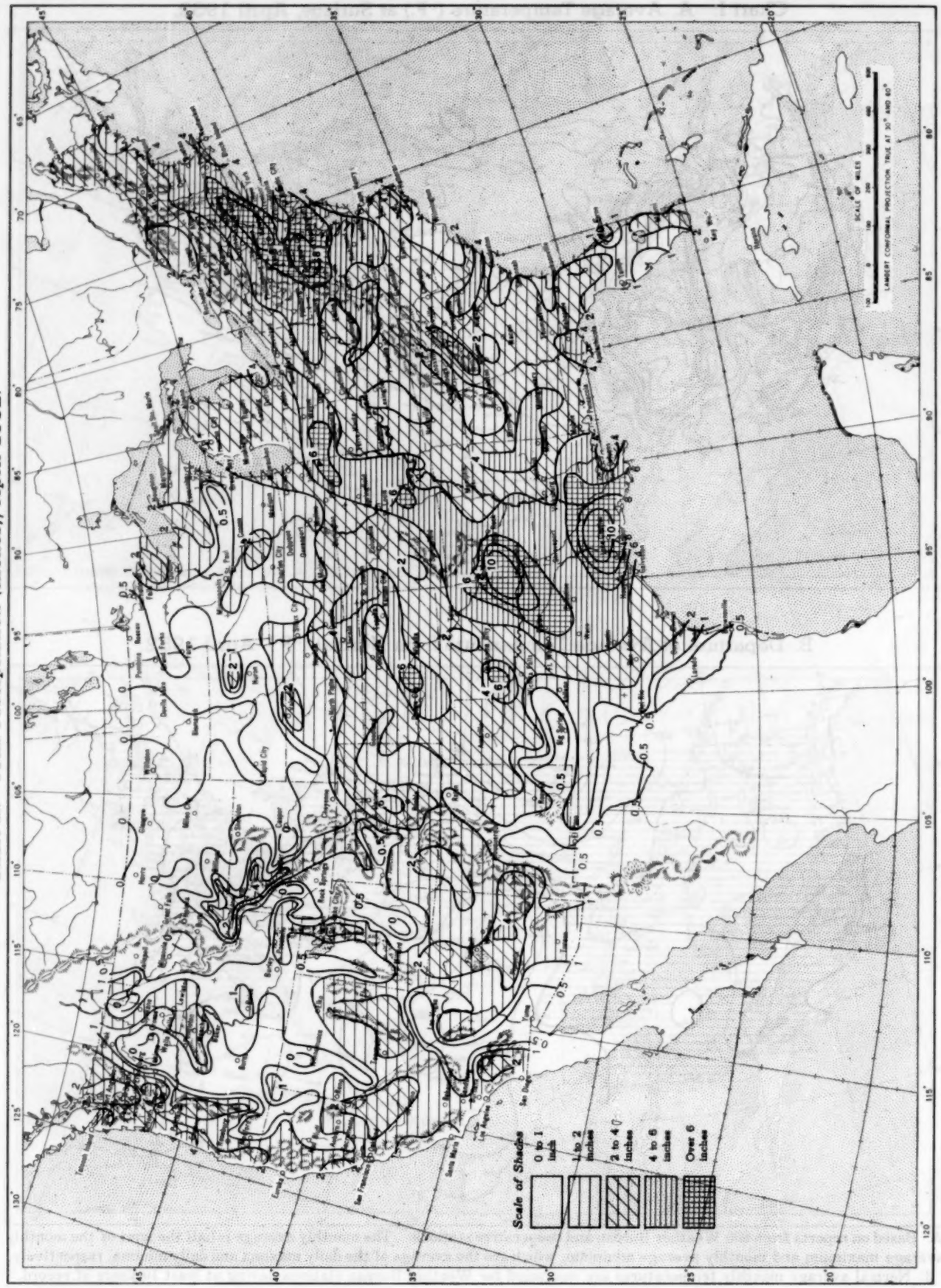


B. Departure of Average Temperature from Normal (°F.), April 1952.



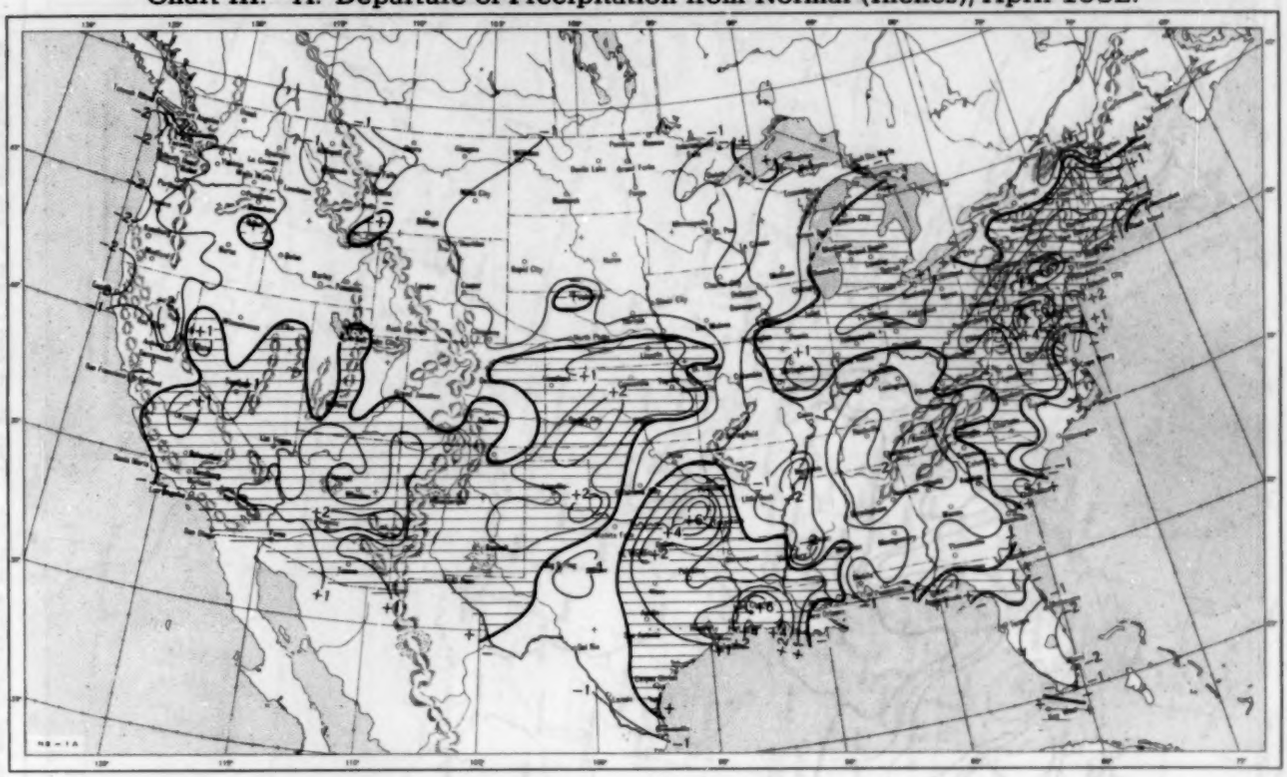
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), April 1952.

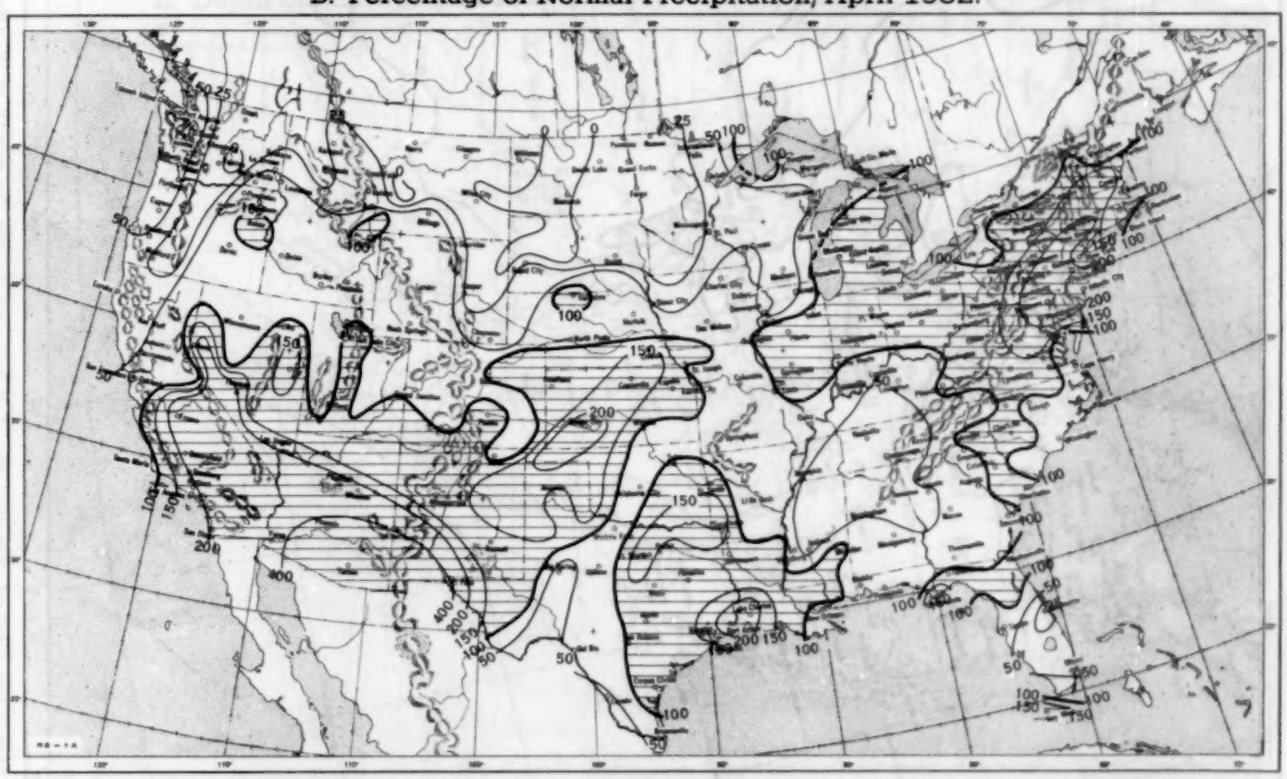

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°
SCALE OF MILES

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), April 1952.

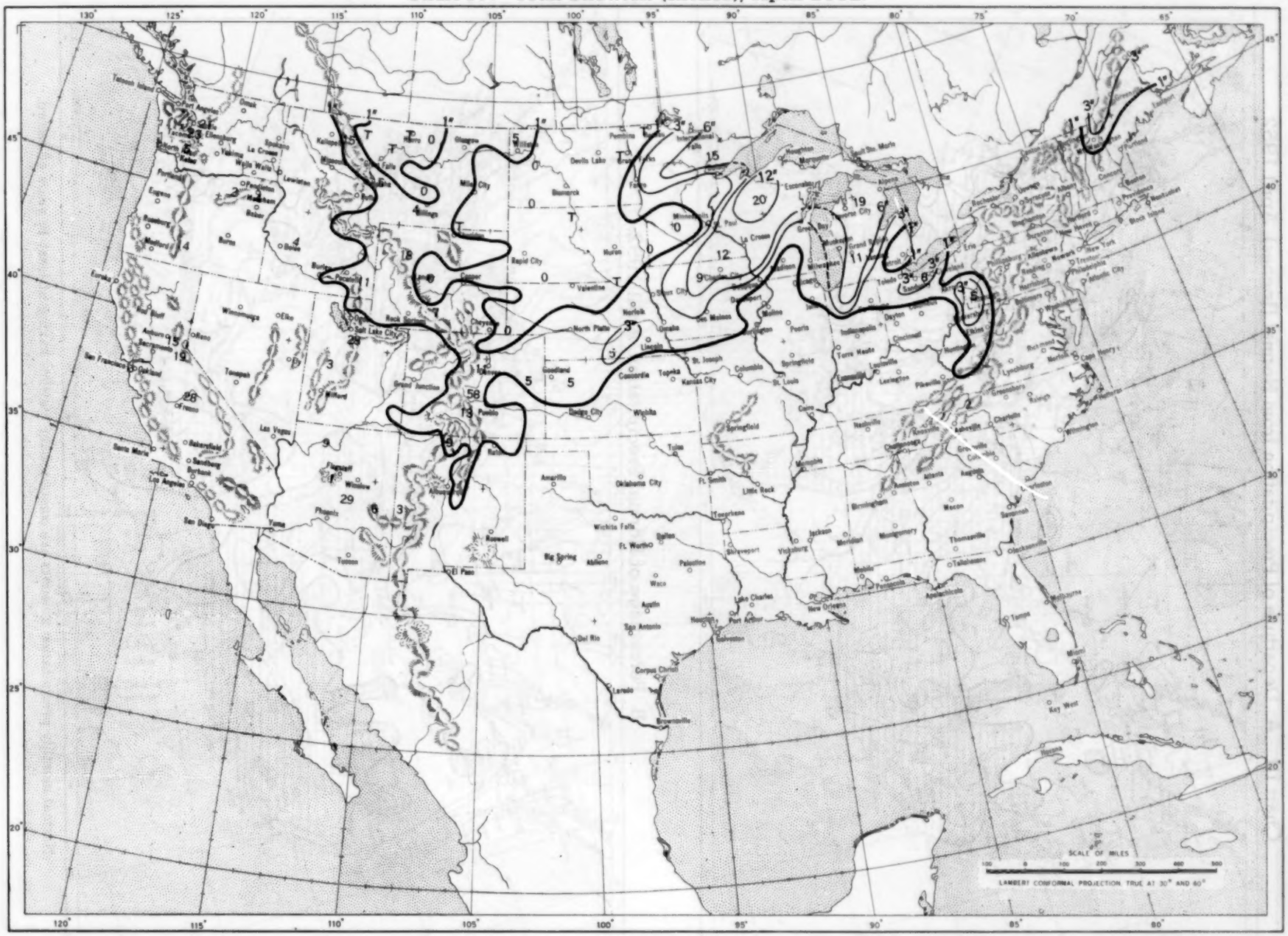


B. Percentage of Normal Precipitation, April 1952.



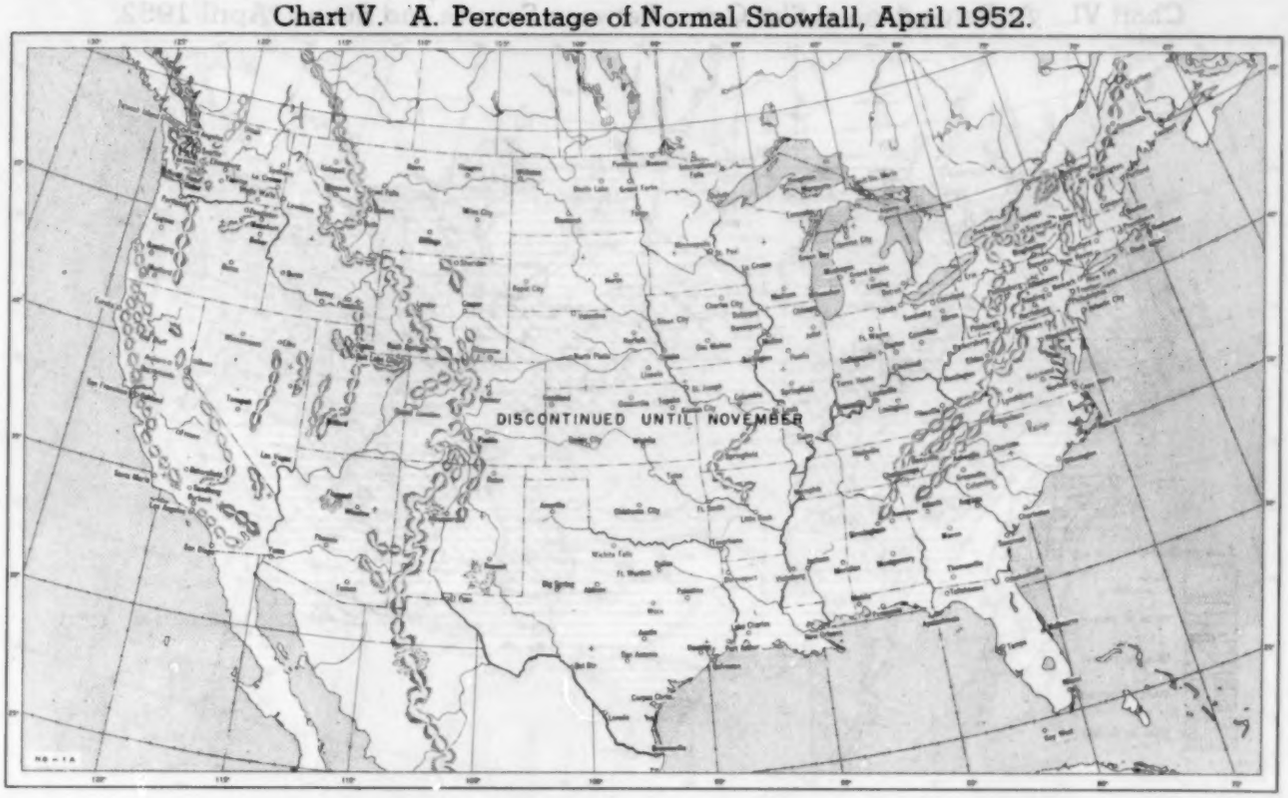
Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), April 1952.



This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

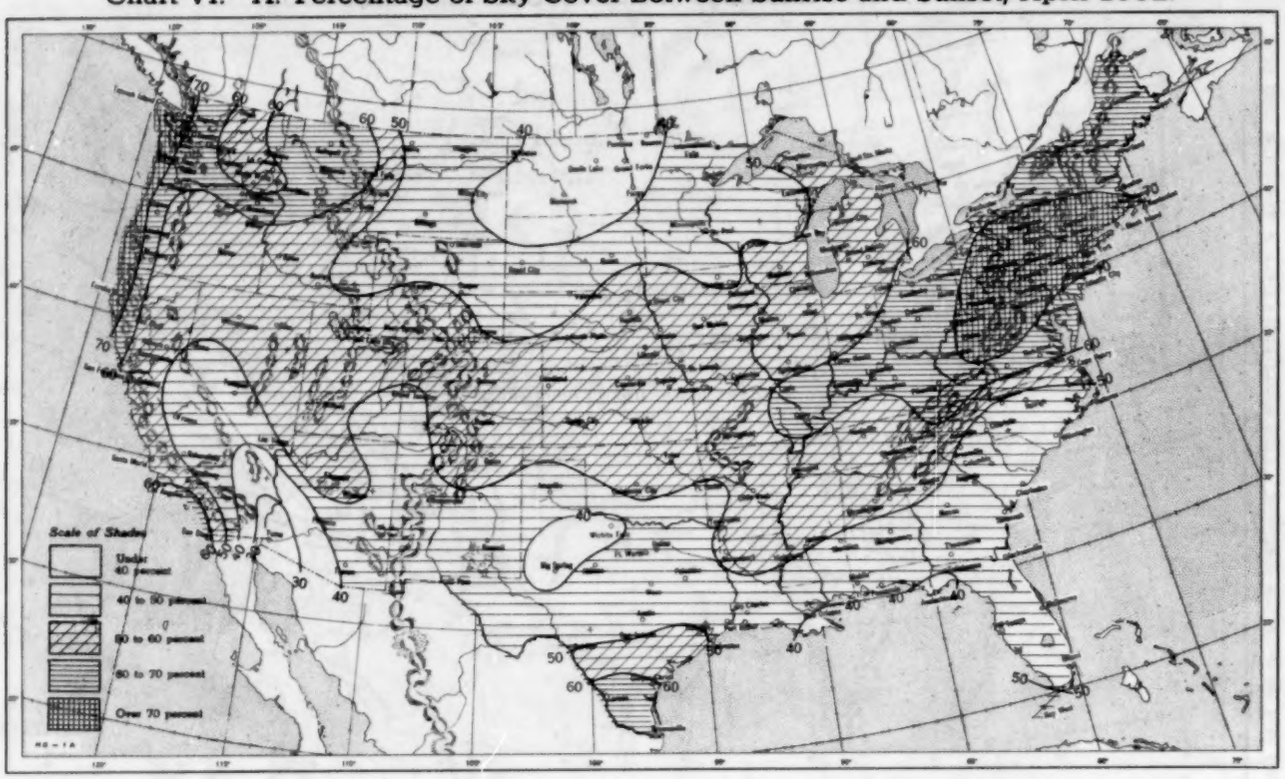
Chart V. A. Percentage of Normal Snowfall, April 1952.



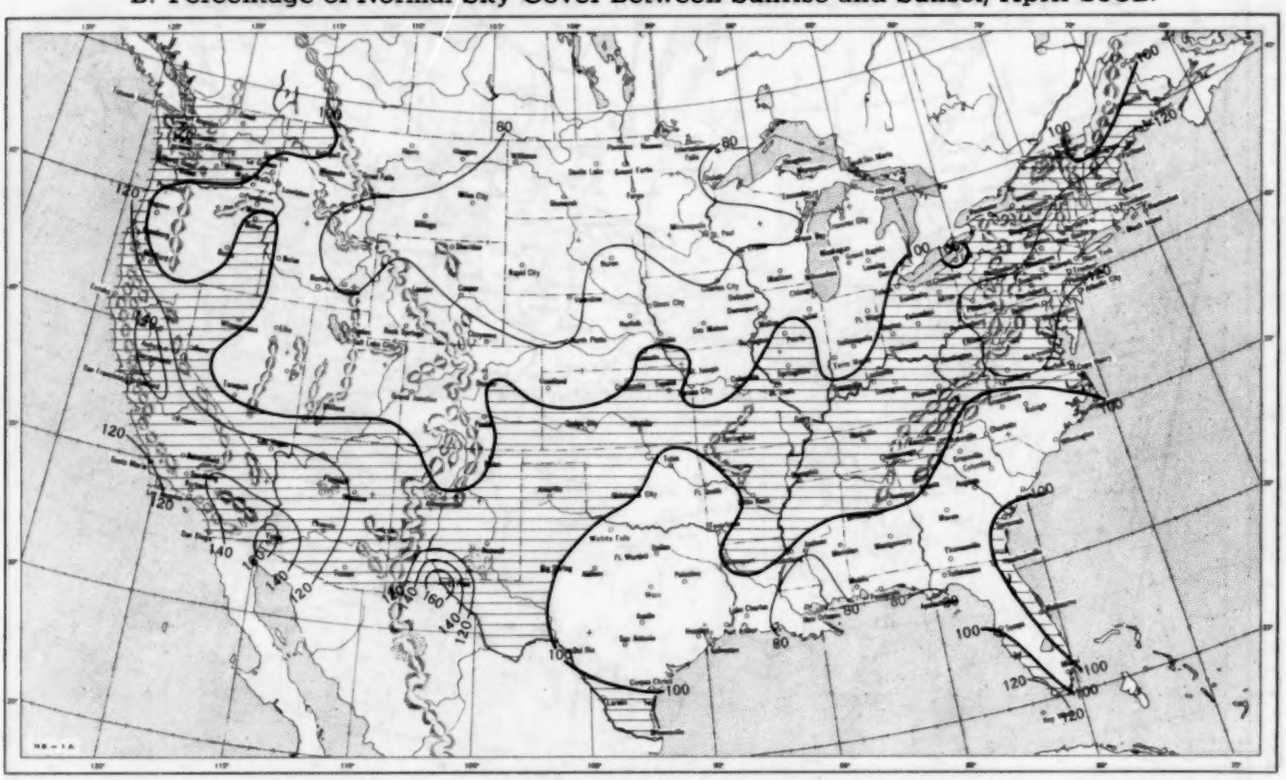
B. Depth of Snow on Ground (Inches), 7:30 a. m. E. S. T., April 29, 1952.

A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E.S.T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, April 1952.

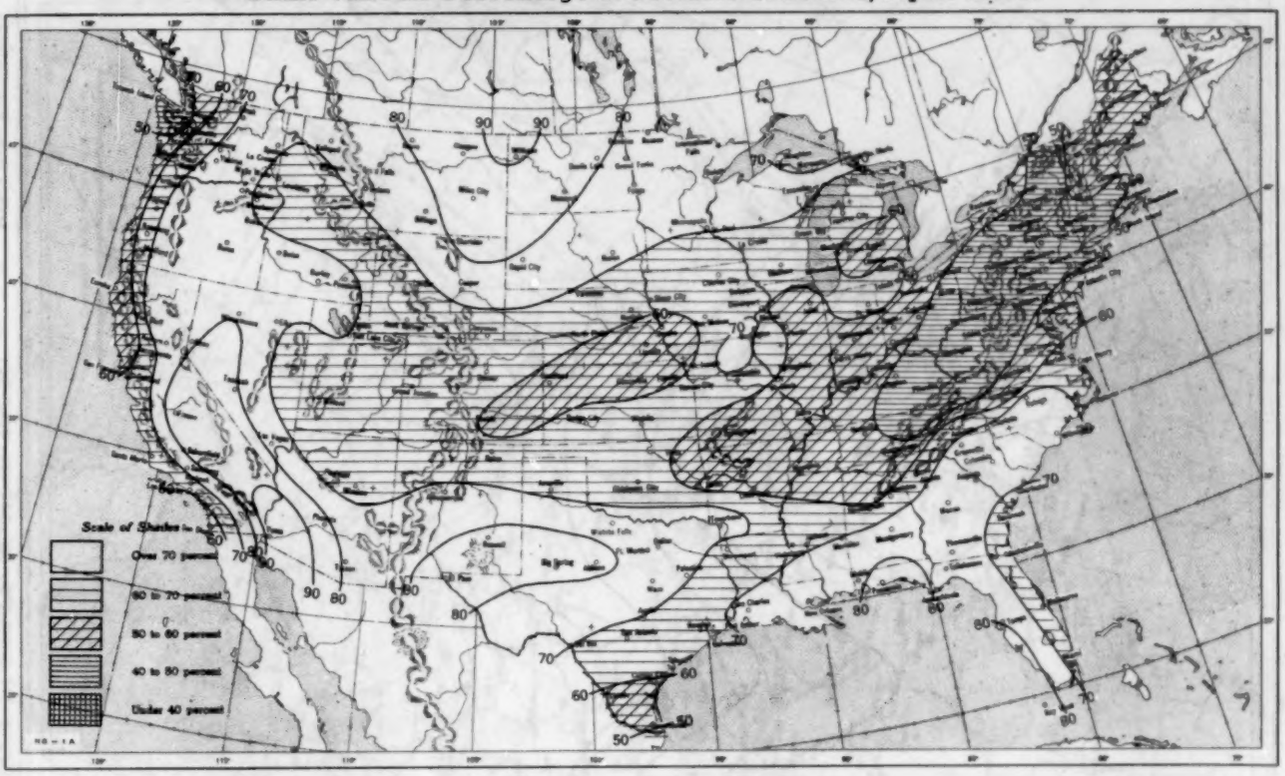


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, April 1952.

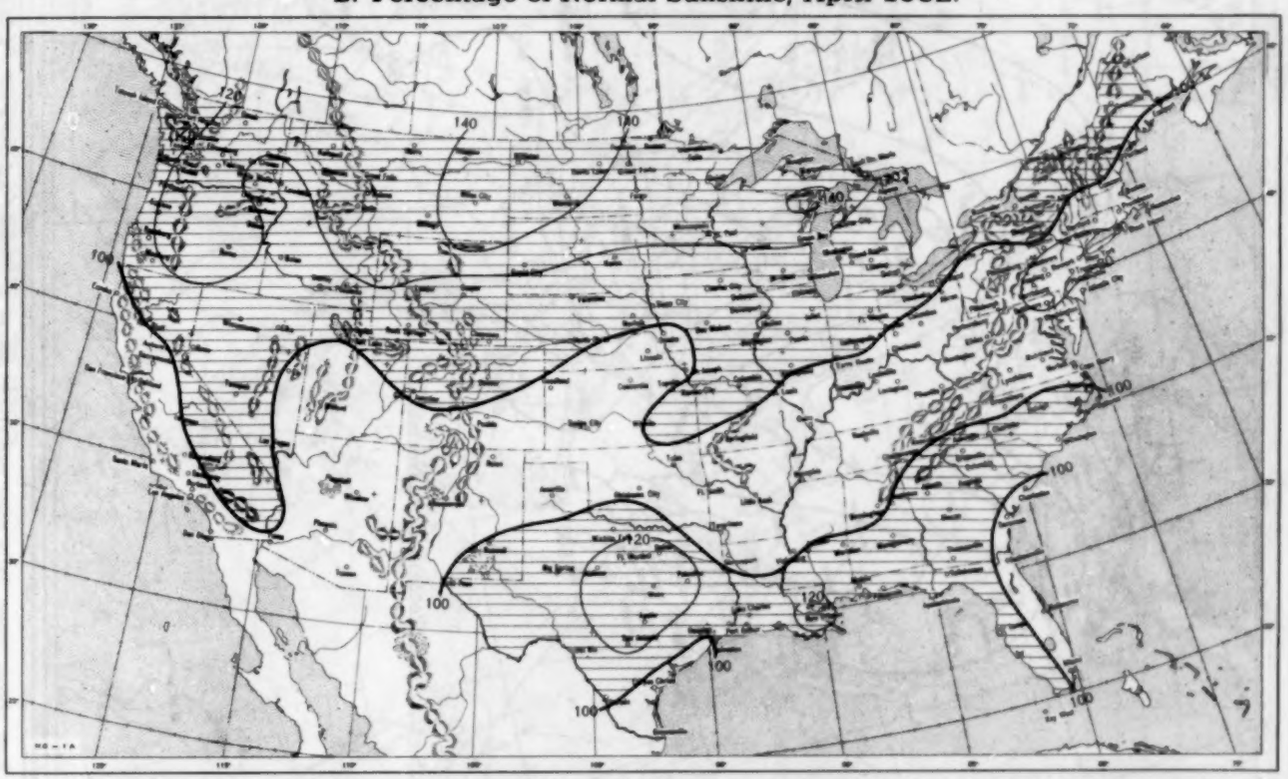


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, April 1952.



B. Percentage of Normal Sunshine, April 1952.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, April 1952. Inset: Percentage of Normal Average Daily Solar Radiation, April 1952.

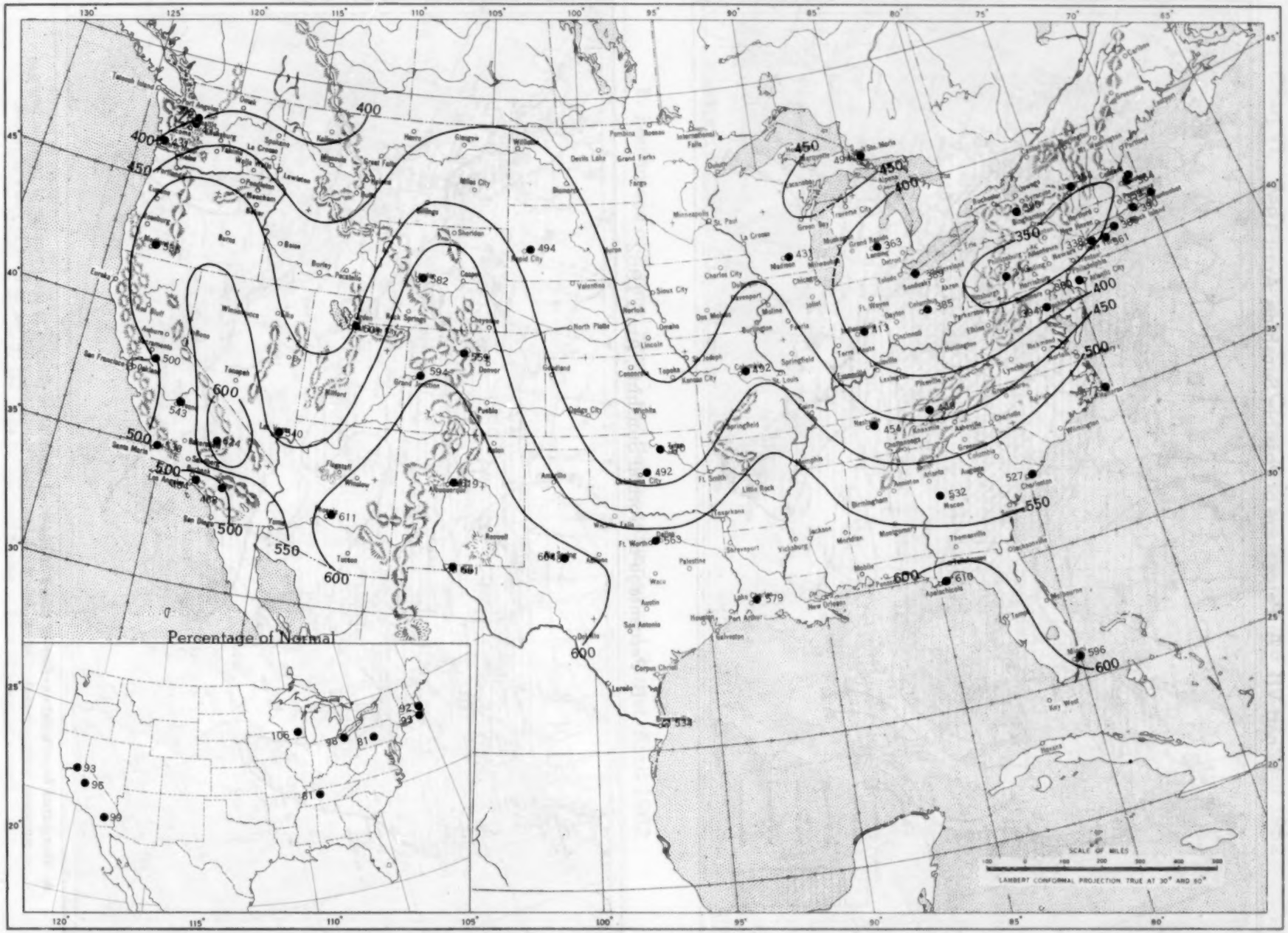
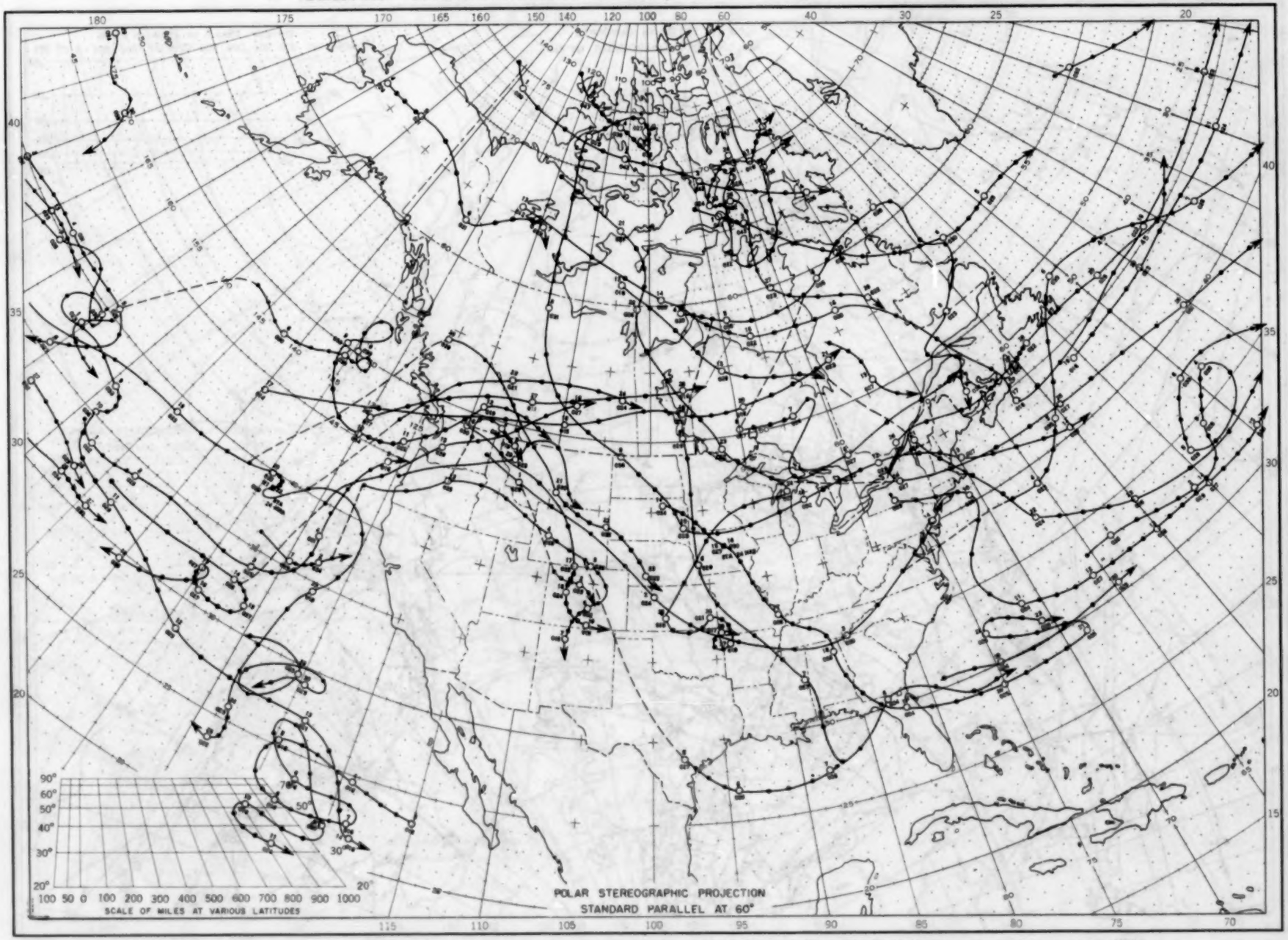


Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

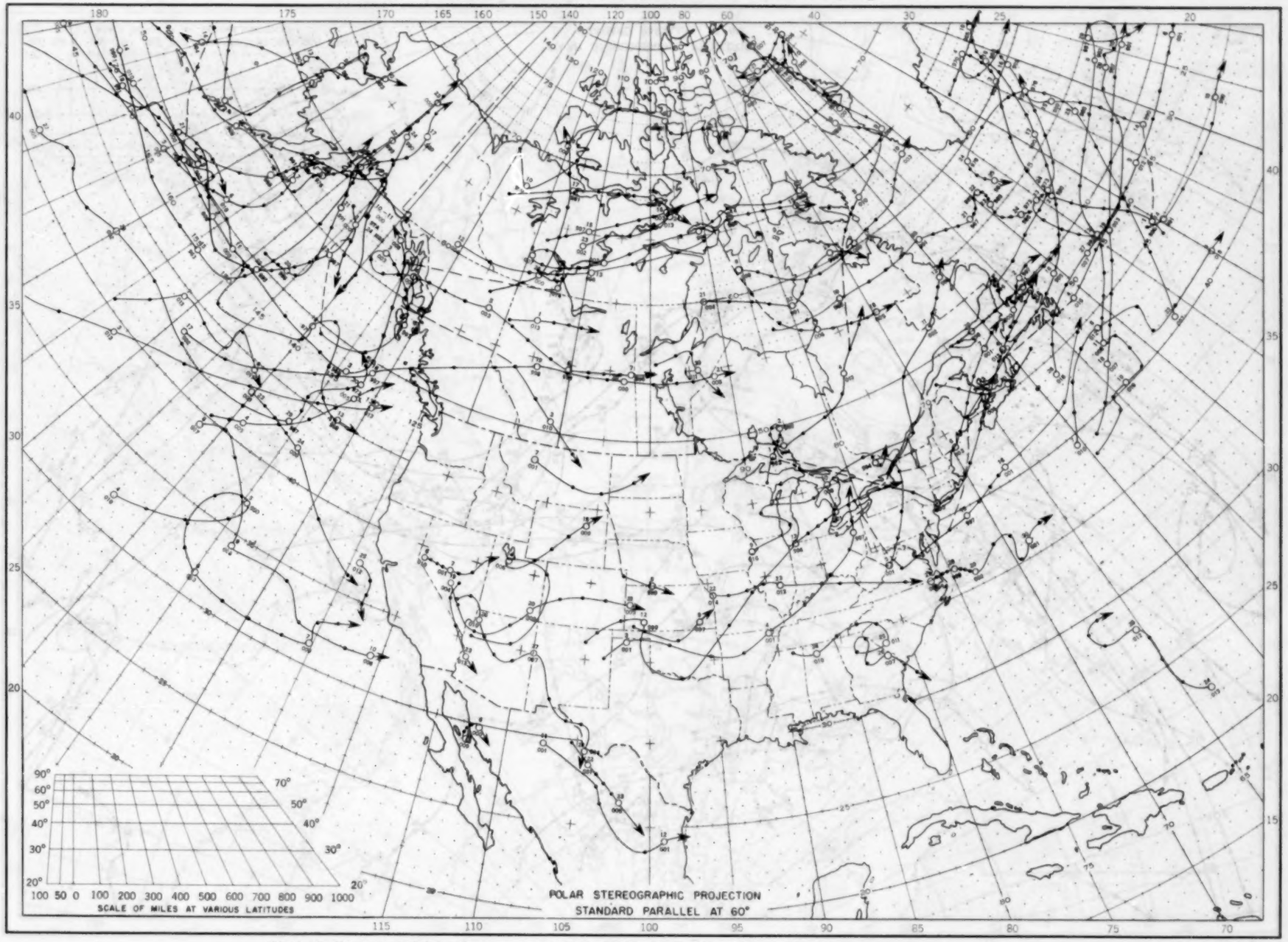
are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, April 1952.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000

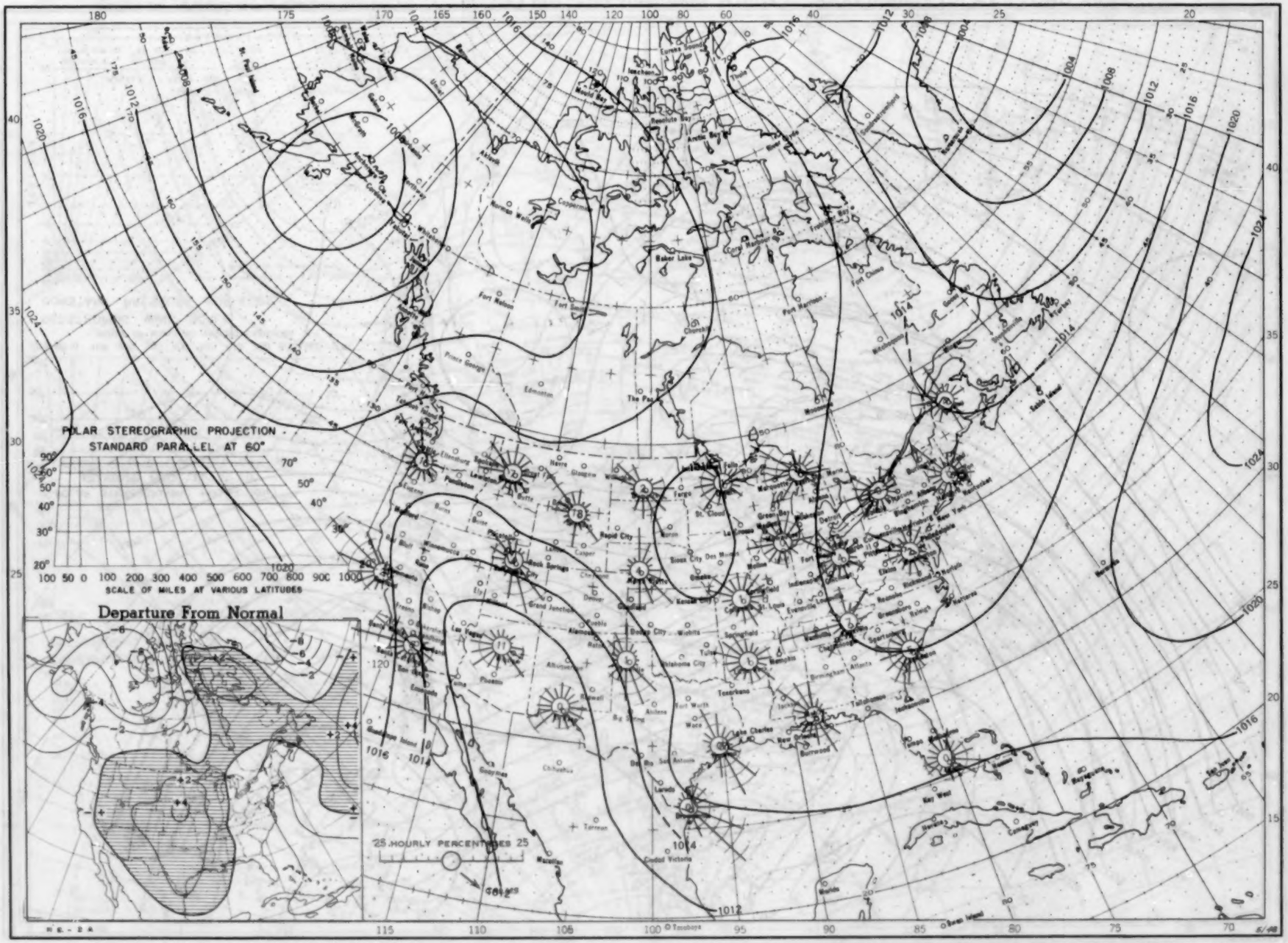
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, April 1952.


SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000
POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

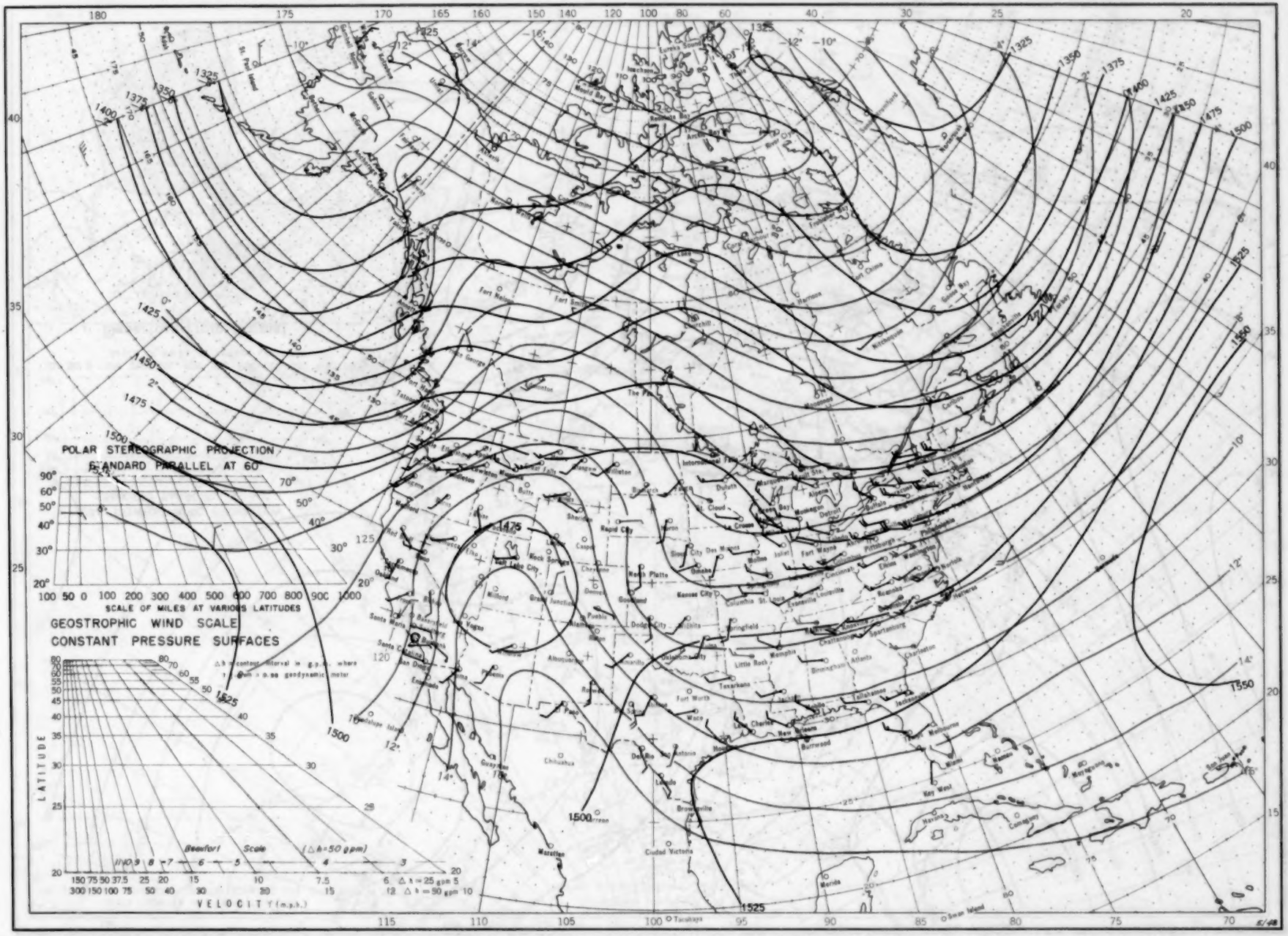
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, April 1952. Inset: Departure of Average Pressure (mb.) from Normal, April 1952.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
Departure From Normal
25 HOURLY PERCENTAGES 25

Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

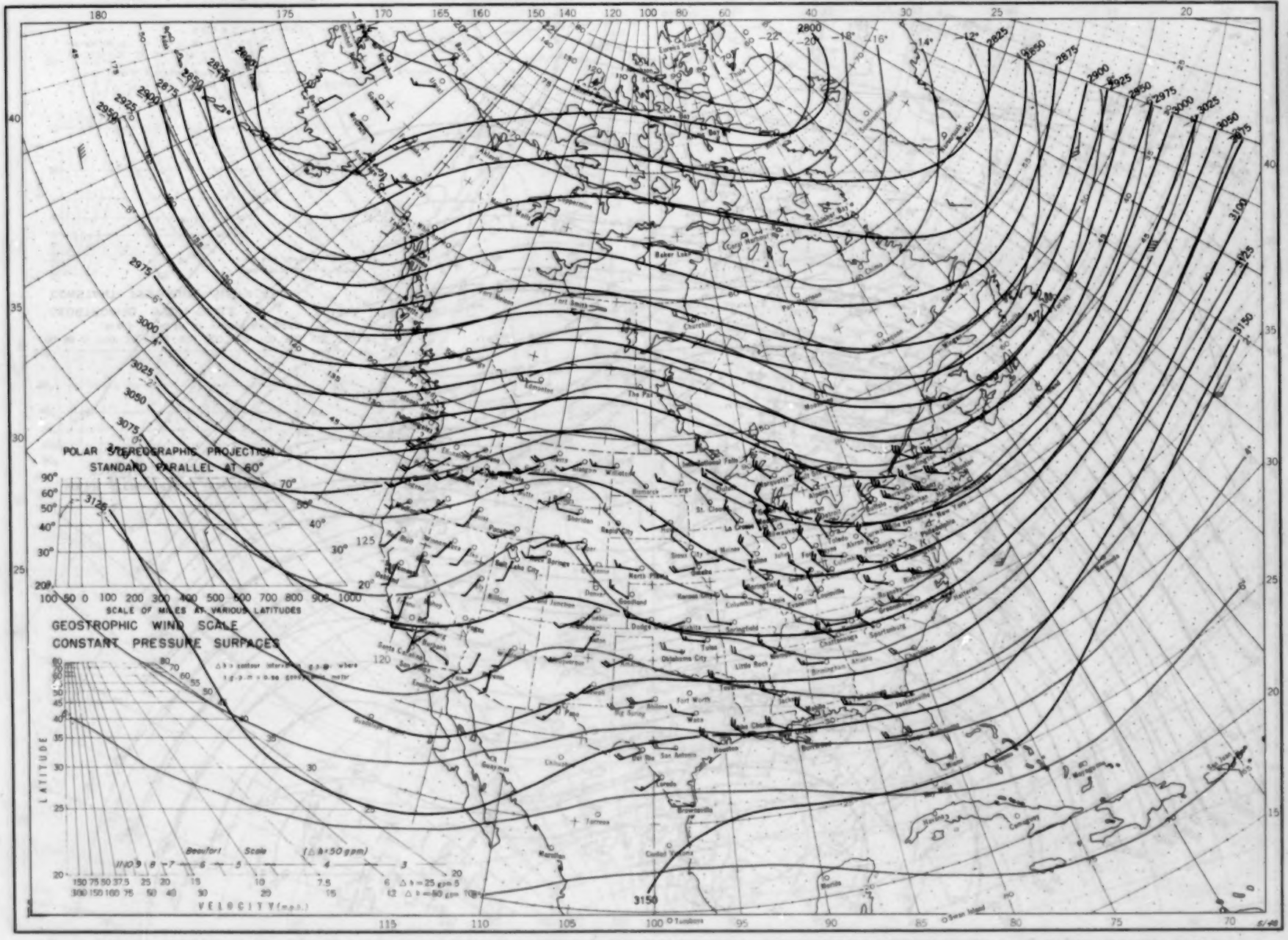
Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), April 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

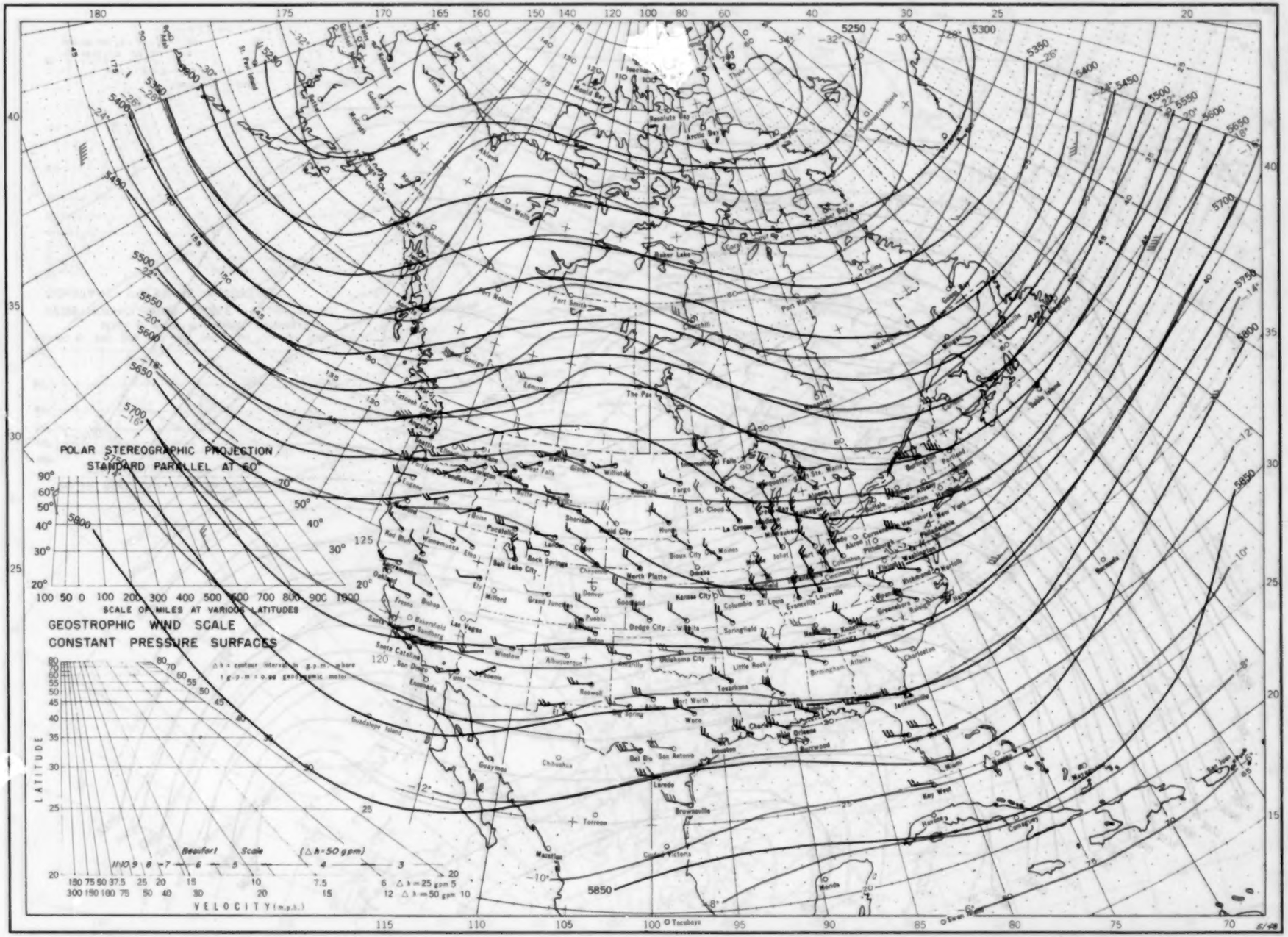
those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), April 1952.



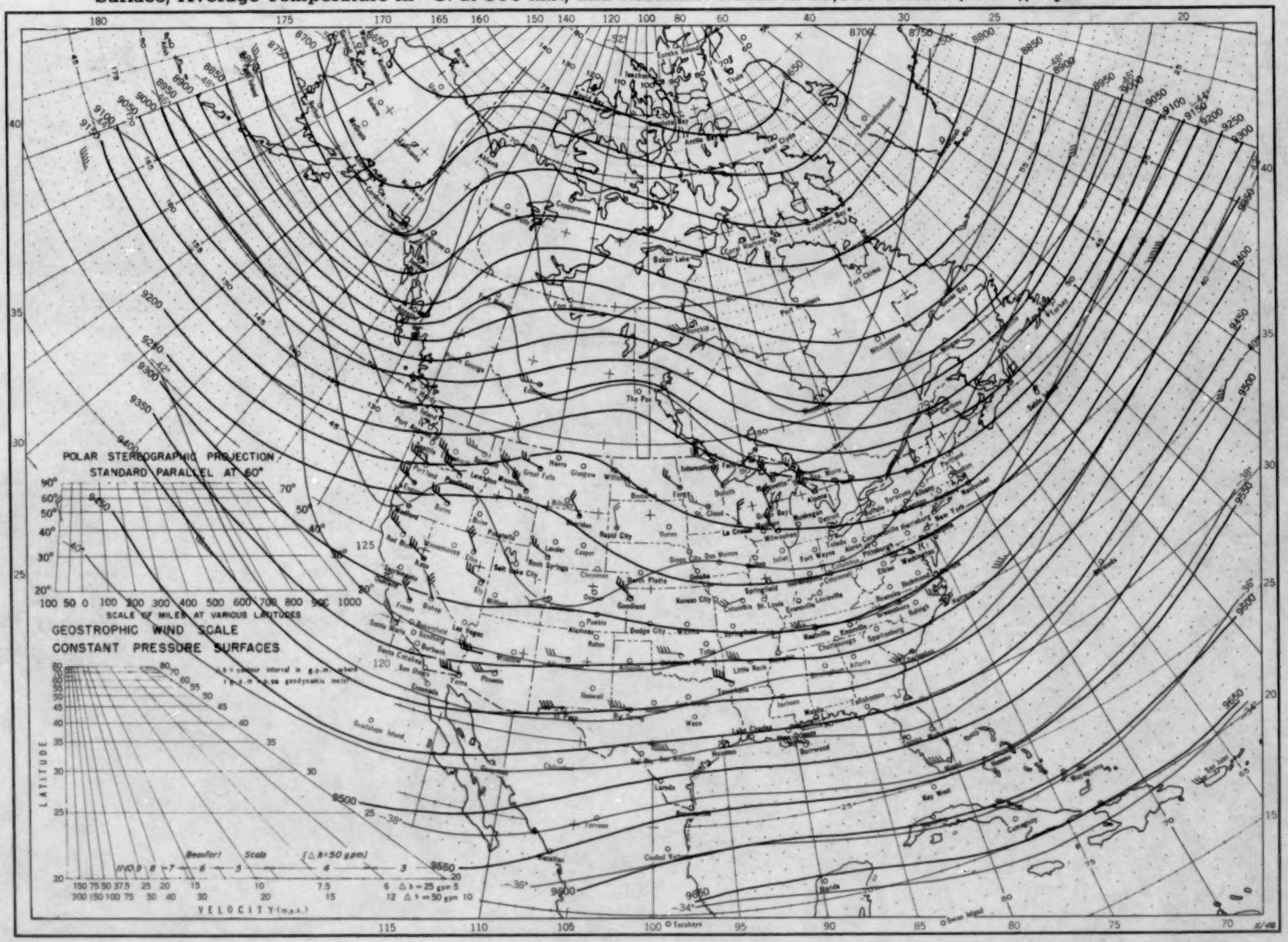
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), April 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), April 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.